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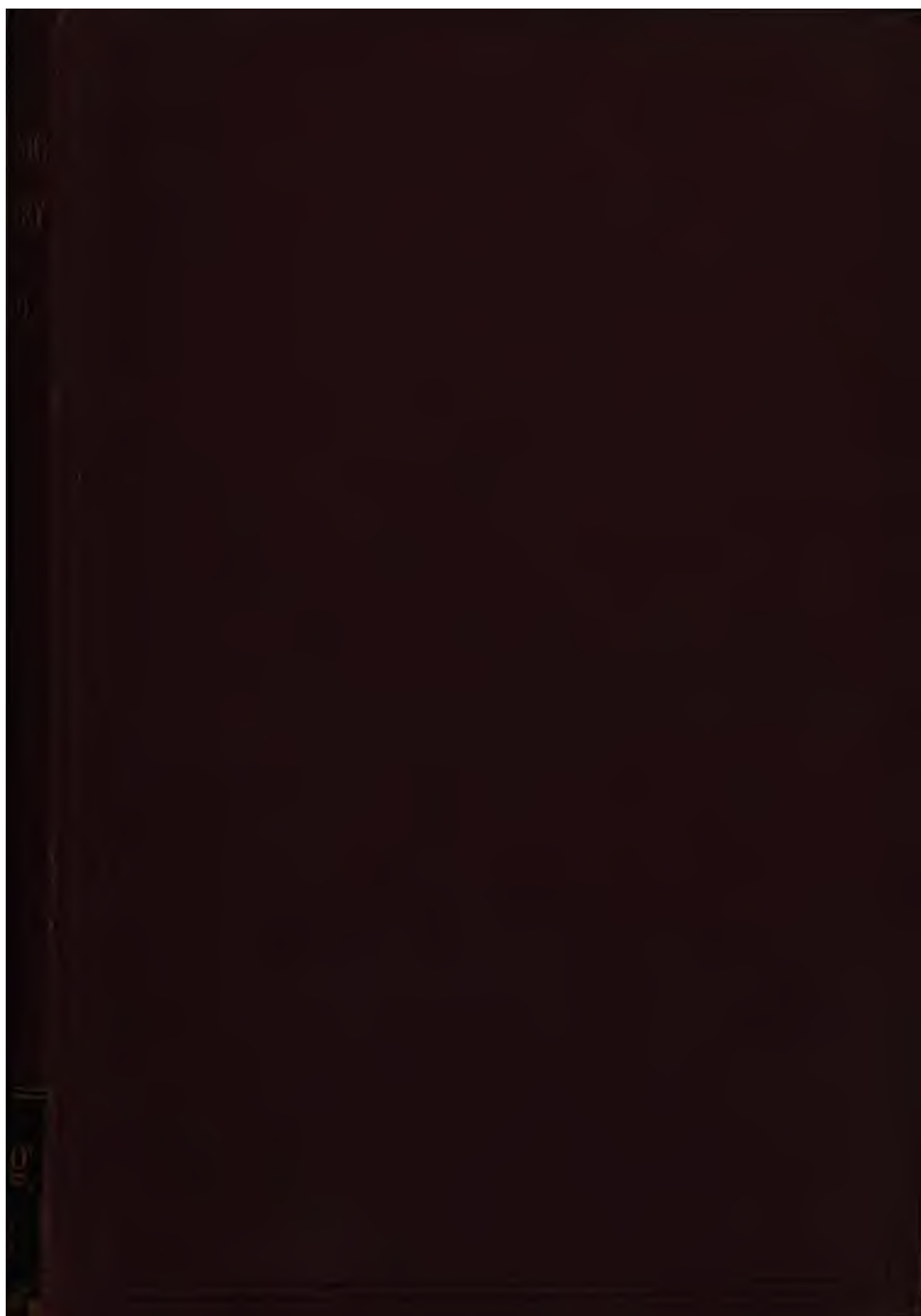
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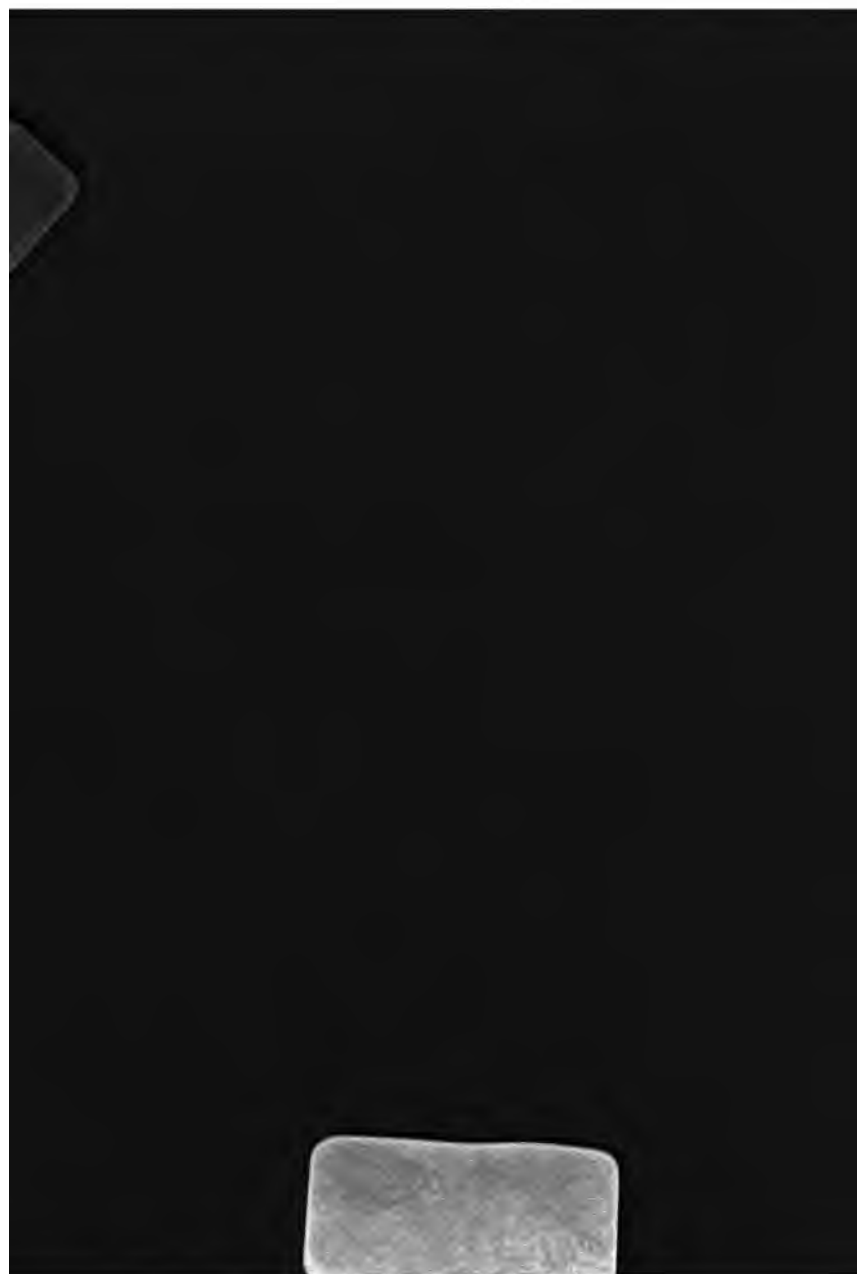
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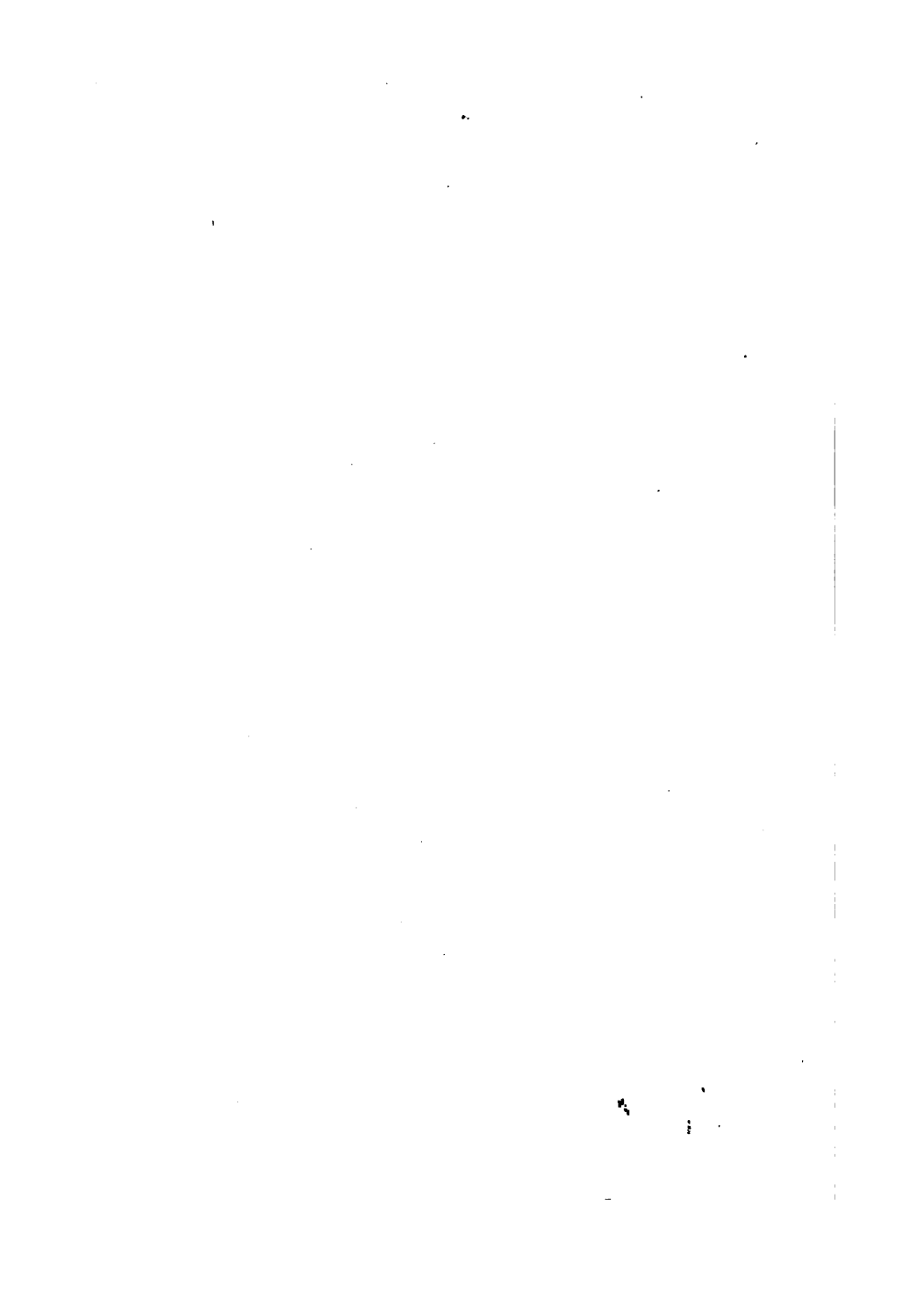
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1. The first step in the process of creating a new product is to identify a market need. This involves conducting market research to determine what consumers want and what problems they are trying to solve.

2. Once a market need has been identified, the next step is to develop a concept for a product that addresses that need. This involves brainstorming ideas and selecting the most promising one.

3. The third step is to create a prototype of the product. This allows the designer to test the product and make any necessary adjustments before moving forward with production.

4. After the prototype has been tested and approved, the next step is to develop a business plan. This includes determining the cost of production, the pricing strategy, and the marketing plan.

5. The final step is to launch the product into the market. This involves manufacturing the product, distributing it, and promoting it to consumers.

6. Once the product is in the market, the designer must continue to monitor its performance and make any necessary adjustments to improve it.

7. The final step in the process is to evaluate the success of the product. This involves comparing the product's performance to the goals set in the business plan.

8. If the product is successful, the designer can use the lessons learned to inform the development of future products.

9. If the product is not successful, the designer can use the feedback to make improvements and try again.

10. The final step in the process is to celebrate the success of the product and the team that created it.

11. The final step in the process is to continue to innovate and create new products that meet the needs of the market.

12. The final step in the process is to continue to learn and grow as a designer and as a business.

INORGANIC CHEMISTRY

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AND PARLIAMENT STREET

INORGANIC CHEMISTRY

THEORETICAL AND PRACTICAL

AN ELEMENTARY TEXT-BOOK

DESIGNED PRIMARILY FOR STUDENTS OF SCIENCE CLASSES
CONNECTED WITH THE SCIENCE AND ART DEPARTMENT
OF THE COMMITTEE OF COUNCIL ON EDUCATION

BY

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P R E F A C E.

THE teacher of classes which are in connection with the Science and Art Department has to face special difficulties. In addition to his desire to give his students a thorough knowledge of their subject, and particularly those portions which have a special application to the industries in which they are engaged, he must necessarily remember that it is all-important to him that good results be obtained at the Department's examinations. Unless, therefore, he is prepared to sacrifice the true teaching of the subject altogether, he must perforce keep in view two ends that are distinct from each other.

The writer of a special text-book such as this encounters the same difficulty: there is, on the one hand, the strong temptation to treat the subject so as to give a sound elementary basis of knowledge, regardless of examiners and examinations; or, on the other, to study the idiosyncrasies of particular examiners, and simply to provide the material for answers to their questions.

The Science and Art Examination *in Chemistry* is unanimously conceded to be a fair one ; aiming at no more than should be expected from students with even the limited opportunities of study which evening classes afford. This minimizes the difficulty of reconciling true teaching with examination preparation. In writing and preparing this little work, I have throughout borne in mind the particular sections of the subjects with which students are expected to be acquainted, and have endeavoured to clearly explain them. Where I have felt it necessary, I have introduced explanations of laws not specifically mentioned in the syllabus, but a knowledge of which, I am convinced, renders the subject-matter of that syllabus more easy of comprehension, and at the same time causes the elementary teaching of chemistry to be a surer foundation on which to base the further acquisition of a more extended knowledge of that science.

In explaining atomicity, the laws of combining proportions, and kindred parts of the subject, I have avoided mention of the possible modifications which may have to be made in our views on these points ; but in order that the student may not be taught anything which is erroneous, I have indicated those bodies which are exceptions to the general rules. The definitions of atomic weight, &c., might have been made more concise, and apparently simpler, but to have done this would necessitate after-explanations which would appear contradictory ; and there is no gain in teach-

ing a law by a simple statement which in the future has to be in great part unlearned.

The student should first read through each chapter, and the laboratory hints given at the close, before commencing his experimental work. Although intended primarily for students working under the supervision of a teacher, most of the experiments may be performed by the self-taught student. There are certain experiments which, according to the discretion of the teacher, may be omitted the first time the book is worked through, and afterwards performed.

Feeling that 'science is measurement,' and chemistry essentially so, I have, very early in the work, introduced the use of the balance: one weighing to about a centigram is sufficiently accurate, and is not very expensive; those made by Becker, and sold by Orme & Co., 65 Barbican, London, at 1*l.* 17*s.* 6*d.*, answer admirably. These balances (No. 51), with 500 grams in the pan, turn with 15 milligrams: Their No. 31 set of weights of from 500 grams to a milligram, price 18*s.* 4*d.*, should also be obtained.

Through the liberality of the publishers, I am enabled to thoroughly illustrate this work.

To the able teaching of Dr. Frankland at the Royal College of Chemistry, I am much indebted; and have frequently consulted notes of his lectures, taken by my friend Mr. Calvelly and myself.

For purposes of reference, I have used Miller's 'Elements of Chemistry,' Tilden's 'Introduction to

Chemical Philosophy,' and Reynolds' 'Experimental Chemistry.' I have taken the Table of Atomic Weights, as determined by the researches of Stas, from Professor Roscoe's work on 'Elementary Chemistry.'

My thanks are due to my friends Messrs. Northam and Schröder; to the former, for sketching many of the illustrations used, and to the latter, for reading the rough manuscript.

I have also great pleasure in thanking Mr. C. W. Merrifield, F.R.S., for his kindness in reading the proof-sheets: I am indebted to him for many useful suggestions which I have introduced in the text.

In addition to its use in science classes, I hope this work may be found suitable for students in middle and higher class schools. It embodies the substance of my courses of lectures and laboratory practice at the Brighton School of Science and Art for some years, as well as of teaching, given in other important educational establishments, and to private pupils. I have been gratified by its success in securing high results at the Science and Art, London Matriculation, and Civil and Military, examinations. As a training for more advanced study I feel it has been of value. In now presenting it to the public, it is my desire that it may be similarly useful to a larger circle of students.

W. JAGO.

SCHOOL OF SCIENCE AND ART, BRIGHTON:

September, 1881.

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TEXT-BOOK OF INORGANIC CHEMISTRY.

CHAPTER I. INTRODUCTORY.

PHENOMENA are continually taking place around us to which we give the name of 'chemical actions.' For instance, a piece of bright iron speedily rusts when exposed to damp air ; milk, as a result of exposure to the atmosphere, turns sour and acquires properties strikingly different from those possessed by that fluid when first obtained from the cow ; coal, wood, and a host of other bodies, which are classed together as combustibles, burn on a light being applied to them, leaving in most cases no visible residue beyond a small quantity of ash. It is the function of the chemist to investigate these changes, and ascertain, as far as he can, the nature of the substances participating in the action and its causes. Chemistry, then, is well defined as 'that science which treats of the composition of matter, and of the action and reaction of different kinds of matter on each other.' The word 'matter,' which is here used, is employed scientifically to signify anything which has weight, i.e. which is acted on by gravitation. Stones, earth, water, and even gases, are matter.

There is no science which is not better studied by the aid of experiments than without ; but while this is simply an additional advantage in some other sciences, it is *absolutely necessary* in the case of that of chemistry.

This book is intended, not only as a text-book for theoretical study, but also as a guide to practical work in the laboratory ; the experiments are, for this reason, not referred to descriptively, but instead, practical directions are given for their performance ; except in some few instances, where they are of a nature more suited for the lecture table than to be tried individually by each student of a class.

It cannot be impressed too strongly at the outset that chemistry cannot be thoroughly and efficiently mastered without this work being actually performed by the student, and not merely seen performed. His own mind and hands should put the experimental question to nature, and his own powers of observation must learn to interpret accurately her answer.

The student will find at the close of this chapter some directions and hints for his use on first commencing work in the laboratory. He will, in all probability, have had the advantage of seeing the experiments performed by the teacher during the lecture preceding the laboratory lesson.

The chemical actions referred to in the first paragraph, are characterized by two concomitants : change of appearance, properties, &c., of the substances involved ; and in the latter class by evolution of heat and light.

Matter occurs in three states, solid, liquid, and gaseous ; chemical action is very frequently accompanied by a change from one of these to another.

Experiment 1.—Place in a test-tube some dilute sulphuric acid, in another about the same quantity of solution of calcium chloride ; notice that each is a transparent, colourless liquid. Add the one to the other ; in a few seconds the whole has become a solid mass, and the test-tube may be inverted with only

a few drops of the liquid running out. In this case a new body has been produced, called calcium sulphate, which combines with a portion of the water present to form a solid.

Not only may liquids be converted into solids, but solids in very many chemical changes are transformed into gases.

Experiment 2.—Light a piece of candle ; it gets less by the act of burning, and ultimately would entirely disappear—the solid fat, composed of hydrogen and carbon, is being changed into gaseous compounds. Hold a cold surface, as the outside of a porcelain dish filled with water, in the flame ; it gets blackened, owing to the separation of carbon as soot or lamp-black ; and also becomes wet, through the deposition of water produced by the combination of hydrogen with the oxygen of the atmosphere.

Take a small piece of candle and fix it in a deflagrating spoon ; light it, and place in a glass jar ; it soon goes out ; remove it and add some clear lime-water, shake the jar—the lime-water becomes turbid through the formation of a compound of lime and the carbon dioxide produced by the oxidation of the carbon of the candle.

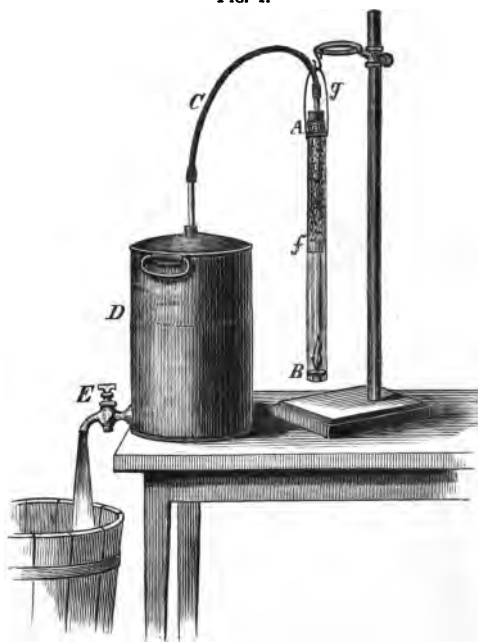
The small wax tapers used for lighting Christmas trees, &c., are very suitable for these experiments.

Although, in burning, the candle disappears, the bodies of which it is composed can thus be traced. By more accurate experiments, in which QUANTITY is estimated, it is found that the WHOLE of the matter present before the combustion still exists after. Matter is indestructible ; and though its form be modified by chemical change, *no alteration in weight takes place.*

Experiment 3.—Take a glass chimney, such as is used for Argand lamps ; fit a cork to each end ; bore several holes in the lower cork, one being in the centre and of a size to fit a small taper, which must be inserted in it. Thrust a piece of wire gauze about two-thirds of the way up the chimney, so as to form a tight plug ; fill this upper chamber with fragments of caustic

soda ; bore a hole through the centre of the top cork, and pass a piece of small glass tubing through. When complete, weigh the whole apparatus carefully ; next place it in a retort-stand and, by means of india-rubber tubing, connect with the short tube passing through the cork of a two-gallon can, filled with water, having a stop-cock at the bottom. Open this cock, and, as the water runs out, it causes a current of air through the

FIG. 1.



apparatus. Take out the taper, light, and quickly replace it ; allow it to burn for three or four minutes, then turn off the cock—the taper goes out ; disconnect the tubing from the top cork and again weigh ; the weight has increased, owing to oxygen having been taken up from the atmosphere by the burning taper ; it has combined with its constituents to form water and carbon dioxide respectively. These compounds are both

absorbed and retained by the caustic soda. The apparatus is shown in Fig. 1. The student, working in a laboratory, will probably find these pieces of apparatus already prepared ready for use. As there is not likely to be a sufficient number for each student to try the experiment at the same time, it must be taken in turns.

Iron may be caused to burn in oxygen, and the oxide thus produced is found when weighed to be heavier than the iron itself was. In the chapter on oxygen, directions will be given for determining this experimentally.

The student who has carefully performed these experiments, will scarcely need to be told that chemical combination is widely different from mere mixture. In the latter case the resultant body is a mean in appearance, specific gravity, &c., between its constituents ; they still each possess their individual properties, and the separate particles may be seen with sufficient magnifying power.

Experiment 4.—Take some finely divided copper ; notice its colour ; mix intimately with powdered sulphur ; the mixture has a tint intermediate to that of the substances when separate. Place some of the mixed powder in an evaporating basin, and wash with a gentle stream of water ; notice that the sulphur is carried away, and that the heavier copper remains behind. This and several other methods may be employed to effect their mechanical separation, which is easily done, as there is no union between them. Next, place some of the mixture in a dry test-tube, and heat ; observe that the sulphur first melts, and that shortly after the whole mass glows brightly. When cool, examine the resulting substance ; it is of a bluish-black colour, brittle, and one of its ingredients can no longer be separated from the other by the action of water or mere solvents. A new body has been formed by the union of the sulphur and copper, known as copper sulphide.

Not only does chemical combination produce bodies different from a mixture of the constituents, but it is also generally accompanied by an evolution of heat. These are

two of the principal characteristics by which a chemical union between substances is detected.

It is well at this early stage of study to have accurate and concise ideas of the meaning attached to the terms, element, &c. Definitions are therefore appended :—

AN ELEMENT is a substance which has never been separated into two or more dissimilar substances.

A COMPOUND is a body produced by the union of two or more elements in definite proportions, and consequently one which can be separated into dissimilar bodies. Compounds differ in appearance and characteristics from their constituent elements.

The term MIXTURE is applied to what is *only* a mixture of two or more bodies in any proportion *without union*. Each component still retains its own properties, and separation may be effected by mechanical means.

The chemical student should make himself acquainted with the relation which exists between chemical action and heat, light, &c. Many brilliant experiments may be made showing the production of light by chemical agency.

Experiment 5.—Place a piece of magnesium wire or ribbon in a flame ; it burns with a dazzling white light, depositing a white, easily powdered body, composed of oxygen and magnesium, and known as magnesia.

Heat a piece of platinum wire in the flame ; notice that it is not in the least altered, not even tarnished, thus showing the very great difference which exists between elements.

In the experiments hitherto performed the operations have been of the kind known as ‘*synthesis*,’ that is, the putting together of elements and building up new compounds. Another most important mode of chemical investigation is ‘*analysis*,’ which consists of decomposing bodies, resolving them into their elements or simpler compounds.

Experiment 6.—Place some red mercuric oxide, about as much as could be held on a threepenny piece, in a dry test-



tube ; close the mouth *loosely* with the thumb, and apply heat. Notice that the colour changes from red to black, the oxide gradually disappears, and minute globules of metallic mercury condense on the upper part of the tube. Next light a splinter of wood, a match will do very well ; when well lighted blow out the flame, and introduce it while still glowing into the tube ; it immediately again bursts into flame, thus showing the presence of the gas, oxygen.

In this experiment a compound has been separated into its two elements ; in order to effect this change, heat has been used and has disappeared as such, being stored up in the elements in the form of the available energy of chemical attraction or affinity. If the mercury and oxygen are again caused to combine, the act of reunion will once more set free the exact amount of heat necessary to effect their decomposition.

Further, by proper appliances, chemical action may be caused to produce electricity ; and electricity in its turn is competent to dissociate the elements of compound bodies.

Force being defined as 'that which is capable of setting matter in motion,' it is evident that chemical action must take its place as one of the forces ; for the combustion of coal, which is a chemical action, generates heat, and, in the steam-engine, is our greatest agent of locomotion.

Matter is maintained in its normal state through the Universe by the action of three most important forces, gravitation, cohesion, and chemical attraction. The first of these acts through all space, and exerts an attraction between all matter. Cohesion acts only across non-appreciable distances, holding together the particles of solids, and also, though to a much less extent, those of liquids.

Experiment 7.—Attach a clean glass plate about 4 or 5 inches in diameter to pieces of wire in the same way as a scale pan is suspended from the end of the arm ; place it in a basin of water, so that the glass plate just floats on the surface ; notice the pull necessary to tear it away from the water and overcome



the cohesion existing between its particles. The amount of this cohesion may be approximately measured by suspending the glass plate from the arm of a balance, and counterpoising it in air: the plate is then floated on water and weights added to the pan until the two are separated.

By means of heat, this force may be often overcome; thus, solid ice may be converted into water; a further increase of temperature destroys the remaining cohesion and produces steam, which, in common with all other gases, is devoid of any cohesion between the particles. But, whether as ice, water, or steam, the substance is the same in chemical properties. By application of a more intense heat, however, the steam is decomposed into oxygen and hydrogen. Heat, therefore, not only destroys cohesion, but when sufficiently intense, overcomes the force of chemical attraction which holds the elementary atoms of all compound substances together.

Summary.

Every-day instances of chemical action. Definition of chemistry. Experimental study is essential. Chemical action is accompanied by change of appearance, &c. Liquids into solids. Solids into gases.

Matter is indestructible; in no chemical change is it lost.

Chemical combination is essentially different from mere mixture; not only accompanied by change of appearance, but also by evolution of heat.

'Element,' &c., defined.

Two most important types of chemical action, synthesis and analysis.

Heat is capable of effecting the decomposition or analysis of compounds. The quantity necessary is reproduced when the elements recombine.

Chemical action may generate other forces, as heat and electricity; it is itself, therefore, a FORCE.

Chemical affinity holds together the elementary particles in compound bodies. Heat overcomes it, and dissociates them.

Laboratory Hints.

In the laboratory the student will either have to provide for himself, or be supplied with, a set of apparatus sufficient for the performance of the common experiments. Such a set should include—

Bunsen's burner and iron rose, with 2 feet of india-rubber tubing.

Retort-stand and spring clamp.

Two pieces of iron wire gauze 5 inches square.

Three flasks, respectively of 4, 8, and 16 oz. capacity.

Six test-tubes, 6 inches by $\frac{3}{4}$ inch diameter.

Test-tube brush.

Thistle funnel 18 inches long.

Glass funnel 2 inches diameter.

Dozen assorted corks.

Brass crucible tongs.

Small evaporating basin, about $2\frac{1}{2}$ inches diameter.

Small beaker, $4\frac{1}{2}$ oz. capacity.

Two books of litmus paper, red and blue.

$\frac{1}{4}$ lb. small glass tubing.

Two feet small india-rubber tubing.

Four gas bottles.

Four ground glass plates.

Messrs. Orme & Co., of 65 Barbican, supply the author with these sets of apparatus in boxes at 17s. They keep the sets in stock, and the apparatus is always reliable.

The following apparatus is generally supplied for common use :—

Earthenware pneumatic troughs and beehive shelves.

Deflagrating spoons and caps.

Deflagrating jars, open at top and bottom.

Retorts of various sizes.

Cork borers.

Pestles and mortars.

Aspirator, balance, weights, &c.

The more expensive pieces of apparatus must be obtained, when required, by application to the teacher.

The student should, in the first place, make himself familiar with the names and uses of his apparatus. Let him next carefully and thoroughly clean the glass and porcelain vessels. The

chemicals required will be found as a rule in bottles and jars, so placed as to be readily accessible to the whole of the students ; they should under no circumstances be removed from their places ; the quantity required should be taken in a flask or test-tube, and the bottle immediately restored to its place. A strict adherence to this rule prevents the loss of a great amount of time which would otherwise be spent in searching over the laboratory for bottles, &c.

In getting the chemicals for an experiment, be sure the right ones are taken ; see that concentrated acids are not used where dilute should be employed ; never use pure substances when the commercial will answer the purpose ; do not let the stoppers of bottles lie about or get mixed. Take no more of the substance than you require, and if you happen to have an excess do not return it to the bottle without express permission ; much confusion has been caused by chemicals being replaced in the wrong bottles.

When directions are given that substances are to be *mixed*, solid bodies are to be first *powdered*, and then stirred together until the mixture is as uniform as possible.

Heat is applied to tubes, &c., by means of the Bunsen burner ; before lighting it, see that the holes at the bottom are open ; the flame should be non-luminous ; if smoky, it is a sign that the gas is burning at the lower end of the tube of the burner ; it must be turned out and re-lighted. This catching fire at the bottom is the result of an excess of air entering ; the remedy is to turn on more gas, or partly close the air-holes by turning the ring of the burner over them. In heating test-tubes, the heat must be applied gently at first, with a constant motion of the tube, or, if the tube be fixed, of the burner.

If heating a liquid, never let the flame play on the part of the tube above its surface. When a solid is being heated, if any moisture happen to be present, it condenses in the upper and cooler parts of the tube ; when there is the slightest sign of this, hold the tube almost horizontal, but with the hot part rather the higher ; this prevents the condensed water running back on the hot glass.

The kind of balance usually employed in a laboratory is one having a long index finger depending from the arm, with the point in front of a graduated scale. The swinging of the

balance is shown by this index. When the weights placed in are equal to the body being weighed, it vibrates to an equal distance each side of the zero mark on the scale. The body to be weighed is placed in the left-hand pan, and the weights in the right. When not in use the pans are supported ; by means of a handle they may be raised, and are then free to swing. The pans should always be dropped on their support when weights are being added or removed. The weights used for chemical purposes are those of the metric system ; for their value, &c., the student should refer to the table given in Chapter III. Never touch the more delicate weights with the fingers, but use the forceps found in the box with them ; great care must be taken that they are not soiled or otherwise injured.

A laboratory note-book should always be kept, and an account entered in ink of every operation as performed. This applies with special force to weighing.

At the close of the laboratory lesson wash the glass apparatus, and wipe with a dry cloth any water, &c., from the retort stand, and other articles, which might rust.

CHAPTER II.

MODES OF CHEMICAL ACTION AND SEPARATION.

CHEMICAL attraction or affinity differs in one important particular from the other natural forces. These are capable of acting through distances which are, in many cases, enormous. Heat and light both reach us from the sun, and in doing so travel over ninety millions of miles, but chemical action can only take place when there is absolute contact between the substances participating in it.

Experiment 8.—Hold a red-hot iron bar some inches from a piece of phosphorus about the size of a pea. Observe that the heat travels over the intervening space and the phosphorus is inflamed, i.e. takes fire. (In this and similar experiments the phosphorus, or other inflammable material, should be placed

on a piece of iron or other substance which will prevent the heat injuring the work-bench.)

Magnetism and electricity, in common with heat, act over distances ; a glass rod, when electrified, will cause the leaves of a delicate electroscope, which is some yards off, to diverge.

Experiment 9.—Electrify a piece of ebonite or a rod of shellac by rubbing with warm flannel ; hold it near some fragments of paper or other light objects ; they are attracted. Place a magnet near a suspended magnetic needle ; notice that the one end is attracted and the other repelled, though the two may be six or more inches apart.

Experiments of a most careful character have been made, in order to measure, if possible, the distance through which chemical action can take place ; as a result it has been found that an interval unobservable to the naked eye is sufficient to prevent it.

Experiment 10.—Powder and mix together one part of loaf sugar and two of potassium chlorate. Take about as much of the mixture as can be held on a shilling and place on a stone slab. Dip the end of a glass rod in concentrated sulphuric acid ; bring the rod as close to the mixture as possible, but not touching ; notice that until actual contact ensues no action whatever occurs ; the moment that they touch, the whole mixture is inflamed.

In order that chemical action, once commenced, shall continue, it is necessary that fresh portions of the substances should be brought into contact. The products of such action must therefore be removed as rapidly as formed ; the requisite mobility of particles necessary for this, is best obtained by at least one of the bodies being in the liquid state. Liquidity may be effected in two ways : 1st, by the action of some solvent, of which water is the most common ; 2nd, by fusion.

Experiment 11.—Mix together some dry carbonate of soda and tartaric acid ; no action whatever occurs. Place the mix-

ture in a test-tube, and add water ; the substances are dissolved, and immediately a brisk effervescence ensues through the acid liberating carbon dioxide from the carbonate. Here chemical action is the result of the more intimate contact resulting from solution.

Experiment 12.—Mix together three parts by weight of nitre, two of dry carbonate of potash and one of sulphur. Take a pinch *and no more* of this powder, and place in a small iron dish or ladle. Apply a gentle heat ; as soon as the mixture is fused it detonates violently. The face should not be held near this substance when being heated. The powder ready mixed is generally found in a laboratory. These substances may be preserved together in the solid state for an indefinite length of time, but combination immediately follows fusion.

Although chemical actions vary so much in their character, they can all be classified under the following five heads :—

I. DIRECT UNION.

Several experiments already performed belong to this class, as heating together copper and sulphur ; many other examples will occur to the student as his knowledge of chemistry increases. The combination of hydrogen with chlorine or oxygen, producing hydrochloric acid and water respectively, are striking instances. Directions for the performance of these experiments are given in the chapters on the respective gases.

Experiment 13.—Place a small piece of phosphorus on an iron plate and drop on it a very little powdered iodine. Combination at once occurs, iodide of phosphorus being formed ; the heat evolved inflames the phosphorus, which continues burning.

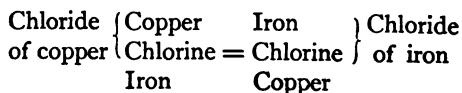
II. CHEMICAL DISPLACEMENT.

The experiment of heating magnesium and platinum wires has already taught us that different elements have various degrees of chemical activity. In certain cases a more active element, that is, one whose chemical attraction

is stronger, is able to displace a weaker element from a compound, and itself occupy the vacant place.

Experiment 14.—In a solution of chloride or sulphate of copper, acidulated with a few drops of hydrochloric acid, place a bright iron rod; on removing it after a few seconds it will be seen to be coated with metallic copper, which has been displaced from its combination with the chlorine, chloride of iron being formed.

The chemical change may be thus represented :—



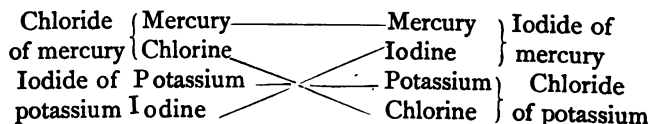
III. MUTUAL CHEMICAL EXCHANGE.

It frequently happens that when two compounds are brought together, an element of each may have a mutual attraction which results in their combination; the remaining elements also combine. An example will render this clear.

Experiment 15.—Place in a test-tube some solution of perchloride of mercury, and add to it, drop by drop, iodide of potassium solution; a red powder is formed, which, from being suspended in the liquid, gradually falls to the bottom. This powder is iodide of mercury. Chloride of potassium remains in solution.

The mercury has exchanged its chlorine for the iodine of the potassium, and the potassium in its turn combines with the chlorine.

The chemical change may be thus represented :—



If in this experiment an excess of iodide of potassium be used, it re-dissolves the iodide of mercury. Whenever a sub-

stance separates from a solution through the addition of another body, as the iodide of mercury has done in this instance, the term *precipitate* is applied to the separated body.

IV. RE-ARRANGEMENT OF PARTICLES.

This is a mode of chemical action of which there are no good examples in inorganic chemistry ; from organic compounds many instances might be cited. In such cases a compound, consisting of certain elements combined in definite proportions, is converted into another in which the properties are different, and yet the composition precisely the same. The change may be compared to the re-arrangement of letters of certain words ; thus the word 'art' may be transposed into 'rat ;' the two words are totally different, and yet the letters are identical.

V. DIRECT DECOMPOSITION.

The resolution of oxide of mercury into mercury and oxygen is an instance of this type of chemical action, which has already been described. The electrolysis, or separation, by electricity, of water into its component elements, is another example with which the student will shortly become acquainted.

The chemist frequently finds, in the course of experiment, that it is necessary to separate bodies from each other ; the processes employed for this purpose are varied, depending on the nature of the substances. As in many future operations it will be necessary to use one or more of them, it is advisable that at this stage they should be studied. There is, as a rule, some particular property which one of the elements or compounds in a mixture possesses which the other does not : thus one may be soluble in water, the other insoluble ; this at once affords a means of separating them. The principal methods of separation employed are solution, decantation, filtration, crystallization, evaporation, distillation, sublimation, and ignition.

SOLUTION, DECANTATION, AND EVAPORATION.—A mixture of two bodies, one only of which is soluble in water, is separated by the action of that solvent.

Experiment 16.—Take some of a mixture of sand and salt, place in a test-tube, add water, and shake up; allow the sand to subside; the clear solution on the top is to be carefully poured off, without disturbing the sediment, into an evaporating basin. This process is known as *decantation*. Place a piece of wire gauze on one of the rings of the retort stand, adjusted at a suitable height above the Bunsen burner; put the evaporating basin containing the solution of salt on the gauze, and light the burner, keeping the flame small; the water will gradually evaporate, and crystals of salt will form. The object of placing the wire gauze under the basin is to prevent the flame coming in actual contact with and cracking it. The water has been driven off by *evaporation*.

In cases where both bodies are insoluble in water, some substance must be selected which acts on the one without the other.

Experiment 17.—Place some of a mixture of sand and chalk or marble in a test-tube, add some distilled water, and heat. Take out a few drops of the water, and evaporate them on clean platinum foil; they entirely disappear, or only leave the slightest stain on the foil. This is the usual test employed to ascertain whether a solvent has dissolved anything or not. Decant off the water and add dilute hydrochloric acid to the mixture; effervescence occurs. When this is over, again take out a few drops of the liquid, and evaporate on the foil; a considerable residue will remain. The best plan to get a few drops out of a test-tube is to put in the end of a glass tube; then close the top with the finger, and withdraw it. On removing the finger, the small portion it contains runs out.

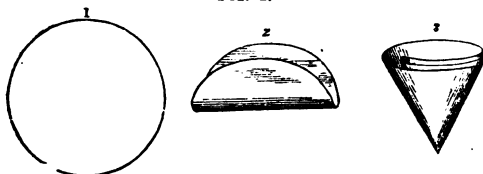
The separation in this experiment depends on the fact that chalk is dissolved by hydrochloric acid, while sand is not affected by it.

FILTRATION.—There are many cases in which decantation is not suitable for the purpose of separating a liquid and solid; the solid body may perhaps be so finely divided that it

remains suspended in the liquid, giving it a muddy appearance. Under these circumstances *filtration* is resorted to.

Experiment 18.—Take a filter paper about $3\frac{1}{2}$ inches diameter, and double it twice; then open it into a cone, taking three folds

FIG. 2.



of paper on the one side and one on the other, as shown in Fig. 2. Place this cone of paper in a glass funnel, which it will just fit, and moisten with water. Care must be taken that the

point of the folded filter does not get broken. Next add to a solution of calcium chloride some ammonium carbonate; a white precipitate is formed. Pour the whole on the filter, holding a glass rod against the lip of the beaker or test-tube down which the liquid runs (Fig. 3); the clear liquid known as the filtrate passes through and must be collected in a beaker; the precipitate, consisting of calcium carbonate, remains on the filter. Pour some clean water on it for the purpose of washing. After this has drained off remove the beaker, push a hole through the bottom of the filter, wash the precipitate into an evaporating basin, and dry it. The filtrate contains ammonium chloride, which may be obtained by evaporation.

FIG. 3.

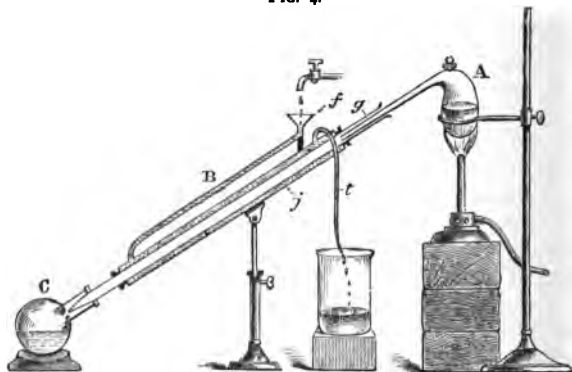


CRYSTALLIZATION.—Where two bodies are mixed together, both of which are soluble in water, but in different degrees, another plan may be adopted for their separation.

Experiment 19.—Take a mixture of about equal parts of potassium chlorate and potassium chloride. Place some in a test-tube, and add just sufficient water to dissolve the whole on boiling; now allow the solution to cool; tabular crystals will separate out, consisting of the less soluble potassium chlorate. When cold, filter these off, just wash with cold water, and dry at a gentle heat.

Separation by crystallization is a process largely used for manufacturing purposes.

FIG. 4.



DISTILLATION.—In the experiments made by evaporation, we have only as yet dealt with the solids which remain, but in many cases the liquid is also required. In the laboratory, where pure water is an essential, it is obtained by this process of distillation, in which the steam is again condensed and collected.

Experiment 20.—Take a glass retort, or, what answers the purpose equally well, a copper vessel fitted with a cork and leading tube, and put some brine in it; fix it in the retort stand, and attach by india-rubber tubing to a Liebig's con-

denser, as shown in Fig. 4. The condenser consists of two glass tubes, one fitting inside the other; the steam passes through the inner one, and, as condensed, runs into the flask placed as a receiver. Through the outer tube a current of cold water is passed, which speedily condenses the steam. The pipe conveying the water is attached to the lower end of the condenser. After some water has collected, taste it, and notice that it is perfectly free from salt.

The advantage of a copper vessel for this experiment is that there is no danger of breakage; the required apparatus will be obtained in a laboratory on application to the teacher.

SUBLIMATION.—This is a process somewhat analogous to distillation; it is in fact distillation of substances which condense in the solid instead of the liquid state.

Experiment 21.—Heat a small portion of a mixture of sand and ammonium chloride in a test-tube; dense white fumes are evolved, which condense as a white crust in the upper part of the tube, the sand remaining behind.

Bodies which distil or sublime are termed *volatile*, and those which neither distil nor sublime are said to be *fixed*.

IGNITION.—Occasionally the chemist avails himself of the combustibility of bodies, and burns them off from others which are incombustible.

Experiment 22.—Place some of a mixture of sand and lamp-black or soot on platinum foil, and keep at a bright red heat for some time with the Bunsen; the lampblack will burn off, leaving the incombustible sand behind. It may be mentioned that when directions are given to *ignite* a body, it simply means that it is to be heated intensely; it does not follow that it will burn.

Summary.

Light, heat, electricity and magnetism act over considerable distances; chemical attraction only between bodies in actual contact. Liquidity of one at least of two bodies aids chemical action.

Modes of chemical action :—

I. Direct union.

- II. Chemical displacement.
- III. Mutual exchange.
- IV. Re-arrangement of particles.
- V. Direct decomposition.

Methods of separation employed by the chemist :—Solution, decantation, filtration, crystallization, evaporation, distillation, sublimation, and ignition.

Laboratory Hints.

Great care must be taken in the handling of phosphorus ; it is always kept under water because of its inflammability. If a small piece is wanted, take a stick out of the bottle with a pair of tongs, place it under water, and cut it while there. Dry it by pressing gently between folds of filter paper or a duster. It should not be touched with the fingers.

The student should not forget that sand and solid substances generally should *never* be thrown down the drains, but put into a box or other receptacle specially provided.

CHAPTER III.

WEIGHTS AND MEASURES, ETC.

FOR the complicated system of weights and measures in use in England, most chemists substitute the very simple metric system. The unit of the system is the metre, a rod of platinum deposited in the archives of France, which, when constructed, was supposed to be one-ten-millionth part of the quadrant of a great circle encompassing the earth on the meridian of Paris. The metre measures 39.37 inches. It is multiplied and subdivided by 10 for the higher and lower measures of length.

Kilometre	=	1000 metres	=	39370	inches.
Hectometre	=	100 metres	=	3937.0	„
Decametre	=	10 metres	=	393.70	„

Metric System of Weights and Measures. 21

Metre	=	39'370 inches.
Decimetre	= 0'1 metre	= 3'9370 "
Centimetre	= 0'01 metre	= 0'39370 inch.
Millimetre	= 0'001 metre	= 0'03937 "

The Greek prefixes deca, hecto, and kilo are used to represent 10, 100, and 1000 respectively; and the Latin deci, centi, and milli signify a tenth, hundredth, and thousandth.

The prefixes are used with the same meaning in the other measures. The decimetre is very nearly 4 inches in length; this affords an easy method of roughly translating measures of the one denomination into those of the other. The actual size of a decimetre is given in Fig. 5.

The measure of capacity is derived from that of length, by taking one cubic decimetre as the unit; this is named the litre, the capacity of which and its derivatives in English measures are appended:—

		Cubic inches.	Pints
Kilolitre	= 1000 litres	= 61027.	1760'7
Hectolitre	= 100 litres	= 6102'7	176'07
Decalitre	= 10 litres	= 610'27	17'607
Litre	=	61'027	1'7607
Decilitre	= 0'1 litre	= 6'1027	0'17607
Centilitre	= 0'01 litre	= 0'61027	0'017607
Millilitre	= 0'001 litre	= 0'06102	0'0017607

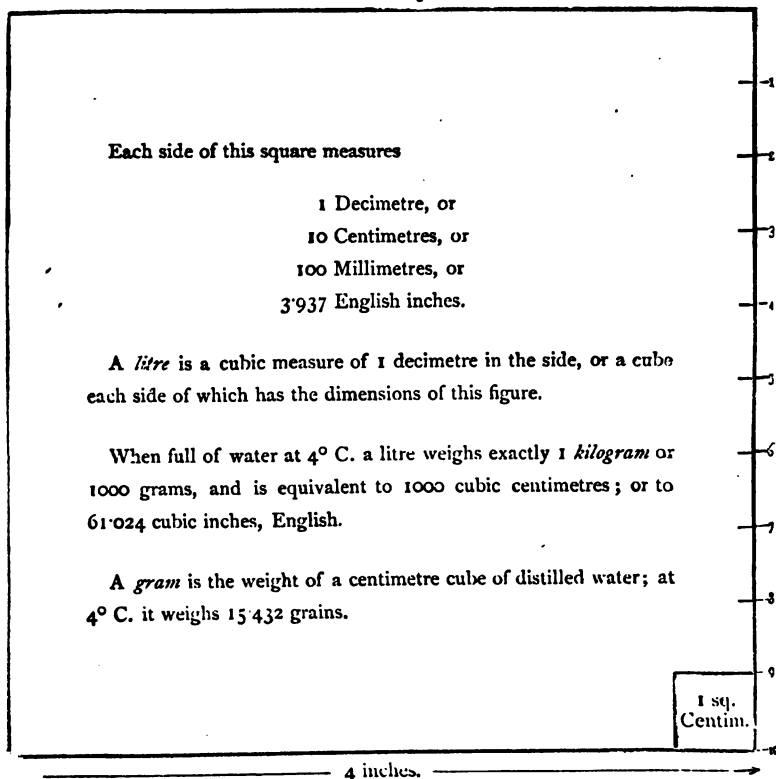
The litre, being the capacity of a cubic decimetre, it is evident that the millilitre equals in volume a *cubic centimetre*; this latter term, or its abbreviation (*c.c.*) is very frequently used in preference to millilitre; thus a pipette is said to contain 50 *c.c.*, and a litre flask is often called a 1000 *c.c.* flask.

The weight of one cubic centimetre of distilled water at its maximum density (4° C.) is taken as the unit of weight, and is called a gramme or gram. The subdivisions and multiples are again the same:—

		Grains.	Avoirdupois ounces.
Kilogram	= 1000 grams =	15432·3	35·2739
Hectogram	= 100 grams =	1543·23	3·52739
Decagram	= 10 grams =	154·323	0·352739
Gram	=	15·4323	0·0352739
Decigram	= 0·1 gram =	1·5432	0·003527
Centigram	= 0·01 gram =	0·15432	0·0003527
Milligram	= 0·001 gram =	0·015432	0·00003527

A kilogram is a little over 2 lbs. $3\frac{1}{4}$ oz., and a hectogram $3\frac{1}{2}$ oz. An ounce avoirdupois equals 28·35 grains.

FIG. 5.



The relation between the weight and volume of water is seen to be a very simple one ; the volume being the same number of c.c. as the weight is grams.

Experiment 23.—Take either a half-litre or litre flask ; see that it is dry, and weigh carefully ; fill to the graduated mark with distilled water, and again weigh ; the weight of the water is either 500 or 1000 grams.

It is assumed that the student is acquainted with English weights and measures ; still the following particulars may be useful :

One gallon of distilled water at 62° F. (16·6° C.) weighs 10 pounds or 70,000 grains ; its capacity is 277·274 cubic inches ; the pint of water therefore weighs 20 ounces. Measures are prepared in which the pint is graduated into ounces ; and at times directions are found in chemical works to add a certain number of fluid ounces of a liquid ; the fluid ounce being the one-twentieth part of a pint. When directions are given to dissolve one part by weight of a solid in 5 or other number of parts by weight of water, either ounces in fluid ounces, or grams in cubic centimetres, may be taken.

THE TEMPERATURE of a body signifies the *intensity* of its heat. Temperature is further defined by Clerk Maxwell as '*the thermal state of a body considered with reference to its power of communicating heat to other bodies,*' and is measured by observing the volume of mercury in a properly graduated instrument when the two are brought in contact. This instrument, called a thermometer, receives heat if its temperature is lower than that of the body, and yields heat if its temperature is higher, until the temperatures of the two are equal. As mercury expands with heat, its volume is an indication of the temperature of any body with which the thermometer is in contact. A thermometer consists of a glass tube with very narrow bore and a bulb blown at the end ; the bulb and a part of the tube being filled with

mercury, a very slight expansion or contraction of the metal in the bulb is rendered visible in the tube or stem.

The temperatures at which ice melts and water boils are always constant, if certain precautions are taken. The height of the mercury at each of these two points is marked on most thermometers. For intermediate temperatures some system of graduation must be employed ; three distinct ones have been devised. Fahrenheit divided the distance between the boiling and freezing points into 180 degrees ; and measured 32 degrees below the freezing point and there marked his 0° or zero ; consequently, on his thermometric scale, the freezing point is 32° and the boiling point $32 + 180 = 212^\circ$. Degrees of equal size are measured both above and below these limits ; those below the zero count downwards as — degrees, thus -20° F. means 20 degrees below zero, or 52 degrees below the freezing point. Degrees above the boiling point simply number upwards, 213, 214° F., &c.

The scale most frequently used by the chemist is that of Celsius, known as the Centigrade scale. The freezing point is the 0° or zero, and the boiling point 100° ; temperatures below zero are reckoned in — degrees. Réaumur terms the freezing point zero and the boiling point 80°.

As 180° F. are evidently equal to 100° C., 1° F. equals $\frac{5}{9}$ ° C. The conversion from the one scale to the other is very simple. As an example, suppose it is wished to know the degrees F. corresponding to 15° C. 15° C., it must be remembered, means 15 degrees *above the freezing point*, and as each degree = $\frac{9}{5}$ F., $\frac{15 \times 9}{5} = 27^\circ$ F. above the freezing point ; but as the freezing point is 32° above the zero, that number must be added, $27 + 32 = 59^\circ$ F. Degrees F. can be converted into degrees C. by the reverse calculation. Both are summed up in the following formulæ :—

$$\frac{C.^{\circ} \times 9}{5} + 32 = F.^{\circ} \quad \frac{(F.^{\circ} - 32) \times 5}{9} = C.^{\circ}.$$

From certain physical considerations it is probable, on the supposition that the phenomena which fall within our range of observation hold generally, that at a temperature of -273°C. , bodies would be *entirely devoid of heat*. This point is frequently called the *absolute zero of temperature*; and the temperature reckoned from this point is termed *absolute temperature*. The absolute temperature of a body is its temperature in degrees C. $+273$.

It is well known that air and other gases expand on the application of heat. The amount of this expansion is expressed in the law : *The volume of gases is directly proportional to their temperature reckoned from absolute zero*. To explain this by calculation, what will be the volume at 1°C. of 273 c.c. of gas at 0°C. ? 0° and 1°C. are represented by 273° and 274° on the absolute scale respectively; then

$$\begin{array}{ccc} \text{Ab. T.} & \text{Ab. T.} & \text{c.c.} \\ \text{As } 273 : 274 :: 273 : 274 \text{ c.c.} \end{array}$$

273 c.c. will therefore have become 274 c.c. at 1°C.

The measure of expansion is sometimes rendered : *Gases expand $\frac{1}{273}$ of their volume at 0°C. for each degree C. increase of temperature*. The above calculation is expressed in the following formula :

$$\frac{V \times (T' + 273)}{T + 273} = V'$$

V is observed volume, T observed temperature, V' calculated volume at T' given temperature.

When gases are measured, it is necessary to reduce the volume to some standard temperature for purposes of comparison; 0°C. is universally employed.

The volume of a gas depends also on the pressure to which it is subject, the one being in inverse proportion to the other. This law is usually referred to as that of Boyle or Marriotte. The *standard pressure* is that of the atmosphere when the barometer stands at a height of 760 millimetres

(m.m.). A lower barometer shows that the gas is subjected to less pressure than the standard, and consequently is more in volume. 0° C. and 760 m.m. are termed therefore standard or *normal temperature and pressure*; the abbreviation N.T.P. proposed by Jones is convenient.

Summary.

The metric system of weights and measures.

Temperature of a body is measured by a thermometer.

Different thermometric scales. Absolute zero.

Relation of volumes of gases to temperature and pressure.

CHAPTER IV.

ELEMENTS, SYMBOLS, AND ATOMIC WEIGHTS.

ALTHOUGH the number and variety of bodies we see around us are practically infinite, yet we find that they are mostly compounds which contain only a few elements. All the compounds known to us are built up from between sixty and seventy elements. Of these but a small number occur plentifully, the rest being only sparingly distributed, while several are present in the earth's crust in only the merest traces. The following table contains a list of the known elements, their symbols, atomicities, where known, and combining or atomic weights. Those printed in capitals are the non-metals or metalloids, those in ordinary type are the commoner metals, those in italics are the rarer metals. The combining weights given are those derived from the experiments of Stas. For most calculations the nearest whole number or whole number with .5 may be employed. Thus chlorine may be taken as 35.5, oxygen as 16, and so on.

Elements, Symbols, and Atomic Weights. 27

Name.	Symbol.	Atomicity.	Combining or Atomic Weight.
Aluminium . . .	Al	IV	27·3
Antimony (Stibium) . .	Sb	V	122·0
Arsenic . . .	As	V	74·9
Barium . . .	Ba	II	136·8
<i>Beryllium</i> . . .	Be		9·0
Bismuth . . .	Bi	V	210·0
BORON . . .	B	III	11·0
BROMINE . . .	Br	I	79·75
Cadmium . . .	Cd	II	111·6
<i>Caesium</i> . . .	Cs	I	133·0
Calcium . . .	Ca	II	39·9
CARBON . . .	C	IV	11·97
<i>Cerium</i> . . .	Ce		141·2
CHLORINE . . .	Cl	I	35·37
Chromium . . .	Cr	VI	52·4
Cobalt . . .	Co	IV	58·6
Copper (Cuprum) . .	Cu	II	63·0
<i>Didymium</i> . . .	D		147·0
<i>Erbium</i> . . .	E		169·0
FLUORINE . . .	F	I	19·1
<i>Gallium</i> . . .	G		
Gold (Aurum) . .	Au	III	196·2
HYDROGEN . . .	H	I	1·0
<i>Indium</i> . . .	In	III	113·4
IODINE . . .	I	I	126·53
<i>Iridium</i> . . .	Ir	IV	196·7
Iron (Ferrum) . .	Fe	VI	55·9
<i>Lanthanum</i> . . .	La		139·0
Lead (Plumbum) . .	Pb	IV	206·4
<i>Lithium</i> . . .	Li	I	7·01
Magnesium . . .	Mg	II	23·94
Manganese . . .	Mn	VI	54·8
Mercury (Hydrargyrum)	Hg	II	199·8
<i>Molybdenum</i> . . .	Mo	VI	95·6
Nickel . . .	Ni	IV	58·6
<i>Niobium</i> . . .	Nb	V	94·0
NITROGEN . . .	N	V	14·01
<i>Osmium</i> . . .	Os	VI	198·6
OXYGEN . . .	O	II	15·96

Name.	Symbol.	Atomicity.	Combining or Atomic Weight.
<i>Palladium</i>	Pd	IV	106·2
PHOSPHORUS	P	V	30·96
Platinum	Pt	IV	196·7
Potassium (Kalium)	K	I	39·04
<i>Rhodium</i>	Rh	IV	104·1
<i>Rubidium</i>	Rb	I	85·2
<i>Ruthenium</i>	Ru	VI	103·5
SELENIUM	Se	VI	78·0
Silver (Argentum)	Ag	I	107·66
SILICON	Si	IV	28·0
Sodium (Natrium)	Na	I	22·99
Strontium	Sr	II	87·2
SULPHUR	S	VI	31·98
<i>Tantalum</i>	Ta	V	182·0
TELLURIUM	Te	VI	128·0
<i>Thallium</i>	Tl	III	203·6
<i>Thorium</i>	Th		231·5
Tin (Stannum)	Sn	IV	117·8
<i>Titanium</i>	Ti	IV	48·0
<i>Tungsten</i>	W	VI	184·0
<i>Uranium</i>	U	VI	240·0
<i>Vanadium</i>	V	V	51·2
<i>Yttrium</i>	Y		93·0
Zinc	Zn	II	64·9
<i>Zirconium</i>	Zr	IV	90·0

The elements termed metals are characterised by being opaque and possessing the peculiar lustre known as metallic. The line of separation between them and the non-metals is not well marked, for the one group gradually passes into the other. Arsenic, which is here included among the metals, is grouped by some chemists among the metalloids; its properties are intermediate. Two of the elements are liquid at ordinary temperatures, mercury and bromine; four, viz. hydrogen, chlorine, oxygen, and nitrogen, are gaseous, but can be liquefied by intense cold and pressure. The remainder are solid. It is only recently that

Characteristics and Distribution of Elements. 29

the condensation of hydrogen, oxygen, and nitrogen has been effected ; hence, from these having before resisted all attempts at liquefaction, the name *permanent gases* was applied to them. MM. Cailletet and Pictet succeeded in obtaining these gases in the liquid form in the last months of 1877.

It has already been stated that of some elements mere traces only have been discovered ; the great mass of the earth's crust is composed of even a more limited number than the remainder. It has been estimated that its average composition by weight is represented by the following table :—

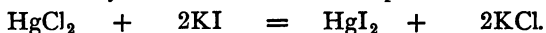
Oxygen	.	.	.	480
Silicon	.	.	.	290
Aluminium	.	.	.	80
Iron	.	.	.	60
Calcium	.	.	.	30
Magnesium	.	.	.	20
Sodium	.	.	.	20
Potassium	.	.	.	15
Hydrogen	.	.	.	2
Other elements	.	.	.	3
				1000

For convenience in describing elements, each has an abbreviation of its full name, called its *symbol*. This is, where practicable, the first letter of its Latin name : where two or more elements commence with the same letter, two letters are selected as the symbol of the less common ; thus carbon, chlorine, and copper (*cuprum*), commence with C. C is accordingly the symbol of carbon, and Cl and Cu of chlorine and copper respectively. The symbols of all the elements, except perhaps those in *italics*, should be learned. A compound body is designated by placing the symbols of its constituent elements together ; for iodide of potassium KI is written, and NaCl represents chloride of sodium. The symbol of a compound body is called its *formula*. The

description of a compound (page 6) states that the elements are present in certain definite proportions. Each element in the table above has a number attached to it, which represents its combining weight, that is, the relative weight of it which enters into a chemical compound; and when KI is written as the formula of potassium iodide, it not only means that that body is composed of potassium and iodine, but also that it contains 39.04 parts of potassium and 126.53 of iodine by weight. There are compounds in which two or more proportions of an element enter, as when iodine combines with mercury: iodide of mercury consists of $126.53 \times 2 = 253.06$ of iodine and 199.8 of mercury; this is shown in the formula by writing HgI_2 . The symbol then of each element represents a definite quantity of that body known as its combining weight; and where multiples of that weight are present in compounds, they are indicated by a small figure placed after the symbol. A large figure placed before it signifies that number of the whole compound. From the law that chemical combination does not alter the weight of bodies, it follows that the weight of a compound is the sum of the weight of the constituent elements.

Chemical actions and changes are most conveniently shown by placing the symbols and formulae of the bodies participating on one side of the sign = and the resultant products on the other.

For instance the action of iodide of potassium and chloride of mercury on each other is thus expressed:—



Mercury Chloride. Potassium Iodide. Mercury Iodide. Potassium Chloride.

Such an expression is termed a chemical equation, and, translated into words, means that one part of chloride of mercury, consisting of one combining proportion of mercury and two of chlorine, together with two parts of iodide of potassium, each of which contains one combining proportion of potassium and iodine, yield or produce one

part of iodide of mercury, consisting of one combining proportion of mercury and two of iodine, and two parts of chloride of potassium, each containing one combining proportion of potassium and chlorine.

As all bodies can be separated into fine particles, it is assumed that chemical action takes place between the finest particles into which a body can be divided ; these particles are called *atoms*.

An *ATOM* is therefore defined as the smallest particle of a substance which enters into or is expelled from a chemical compound : atoms are indivisible.

For the phrase 'combining proportion,' used above, we may employ the term '*atom*,' and the combining weight may also be looked on as the weight of the atom of each substance compared with that of the atom of hydrogen, which, being the lightest, is taken as unity.

The combining weight of an element is a number derived from actual experiment, but that it represents the weight of an atom is an assumption ; for this reason we have in the first place spoken of the quantity of an element entering into combination as its combining proportion. It will be more convenient, however, to use the terms atom and atomic weight ; but it must be borne in mind that while the atomic theory may be modified, the combining weights represent facts. The little group of atoms represented in the formula of a compound is called a *molecule*.

A *MOLECULE* is the smallest possible particle of a substance which can exist alone ; and can only be separated into its constituent atoms. For instance a molecule of iodide of mercury cannot be separated into two particles of that compound : the only decomposition of which it is capable is into mercury and iodine atoms.

When the student's knowledge of chemical facts is more extended, the atomic theory will be explained more fully, and also the experimental basis on which it is founded. It is necessary to have some idea of what it involves, in order

to understand the uses of chemical equations. An exact knowledge of these equations is of vital importance ; the result of every experiment mentioned in this work will be so expressed, and the student must thoroughly master them.

Matter being indestructible, the same number of atoms of each element must appear on each side of the equation.

The column headed 'Atomicity,' in the table of elements, will be referred to and explained in a subsequent chapter.

Summary.

Names, symbols, atomicity, and combining or atomic weights of the elements.

Division into metals and non-metals, into solids, liquids, and gases.

Approximate composition of the earth's crust. Symbols, formulæ, and equations.

Weight of atoms. Definition of 'atom' and 'molecule.' The atomic theory.

CHAPTER V.

OXYGEN.

Symbol, O. Atomic weight, 15.96. Density, 15.96. Specific gravity, 1.1056. Molecular weight, O₂ 31.92. Molecular volume, $\square\square$.

The density of a gas is its weight, volume for volume, compared with hydrogen taken as unity ; the specific gravity is its weight compared with an equal volume of air. Molecular weight and volume are explained in Chapter X.

OCCURRENCE.—Oxygen occurs plentifully in nature, both in the free state, and in combination with other elements. About one-fifth of the atmosphere consists of this gas ; it constitutes eight-ninths by weight of water, and

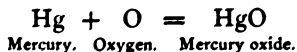
as shown in the table given on a previous page, about 48 per cent. of the earth's solid crust.

DISCOVERY.—Dr. Priestley, of Birmingham, discovered, in 1774, that by heating mercury in contact with air in a closed vessel, the volume of the air was lessened, and that red scales were formed on the surface of the mercury. An

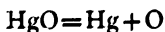
apparatus by means of which the experiment may be performed is shown in Fig. 6. The flask, containing the mercury over the gas-lamp, is connected with a jar of air inverted in a porcelain vessel filled with mercury. By this device the mercury in the flask, while in contact with the air in the jar, is shut off from the atmosphere. The mercury requires to be heated to a temperature just below its boiling point, and the heat maintained for two or three days. On



allowing the apparatus to cool at the close of the experiment, the diminution of the air in the jar may be observed. The red scales produced consist of oxide of mercury. The chemical change may be thus represented :—



PREPARATION.—The student is aware from experiment 6 that oxide of mercury is decomposed into oxygen and mercury by a strong heat—



This experiment should be again repeated and the gas evolved collected.

Before proceeding further, prepare the apparatus for col-

lection of gases, specified in the laboratory hints at the end of this chapter ; also read the whole of the directions there given carefully through.

Experiment 24.—In gas apparatus No. 1 substitute one of the combustion tubes for an ordinary test-tube ; place in it about as much oxide of mercury as could be held on a sixpence ; clamp it in the retort stand, or hold by means of a test-tube holder in the hand (it is preferable to use the retort stand) ; arrange the pneumatic trough and a small gas-jar for the collection of gas, as shown in Fig. 7. The quantity of mercury oxide is much less than that of potassium chlorate mixture which is shown in the figure. Carefully heat the mercury oxide with the Bunsen burner, and observe the evolution of gas. When the jar is full, take it out of the trough and introduce a glowing splinter ; the rekindling shows that the gas is oxygen. A large test-tube may be used if a small gas jar is not obtainable.

Most of the methods employed for the preparation of oxygen are instances of direct decomposition. The substance most frequently used by the chemist is chlorate of potash, which is composed of potassium, chlorine and oxygen. At a comparatively low temperature the oxygen is driven off from this body, a compound of potassium and chlorine remaining behind—



Experiment 25.—Using the same apparatus as that employed in the last experiment, substitute an ordinary test-tube, placing it in about enough potassium chlorate to fill the bottom of the tube half an inch. As this liquefies on the application of heat, the tube must be inclined when fixed in the retort-stand. Heat gently ; at first the salt crackles : this is owing to the crystals being split up by the heat, and is known as *decrepitation*. The chlorate soon melts, and then appears to boil : the salt is really being decomposed. Collect the oxygen over the pneumatic trough and test it.

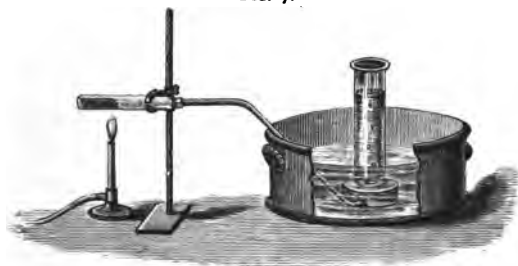
If instead of using potassium chlorate alone, a mixture of that salt with about one quarter of its weight of manganese

dioxide (black oxide of manganese) is employed, the gas is given off much more rapidly and at a lower temperature. At the end of the experiment the manganese dioxide is found unaltered. This mixture is almost always employed for the preparation of the gas, except when required in a condition of absolute purity.

The student will require seven jars of gas for the following experiments : it will be best to prepare them in two lots.

Experiment 26.—One-third fill a six-inch test-tube with the mixture of potassium chlorate and manganese dioxide in the proportions mentioned above : this amount is quite sufficient to evolve the quantity of gas required. Push a wire down to the bottom of the tube, so as to make a clear passage for the gas.

FIG. 7.



Connect the test-tube to the rest of the apparatus used in the last experiment, as shown in Fig. 7, and having three jars ready inverted in the trough, proceed to fill them. Holding the Bunsen in the hand, commence warming the mixture gently at the *top*, *i.e.* the end nearest the cork, and slowly bring the flame nearer the bottom as the gas is evolved. The reason for this is that the mixture cakes on being heated : if heated first at the bottom, the upward current of gas would carry the loose dust of the mixture on with it, and probably choke the leading tube. Withdraw the source of heat when the last jar is about half full : the action will then probably cease as the jar is filled. Remove the end of the leading tube from the trough ; other-

wise, as the hot gas within cools, the contraction would draw up the water and crack the test-tube.

Experiment 27.—To one jar of the gas add some clear lime-water ; replace the plate, and shake up : observe that the lime-water remains clear. In the same jar make the usual test for oxygen.

Experiment 28.—To another jar add some litmus solution, and shake up : notice that the blue colour is unchanged.

Experiment 29.—In the third jar burn a piece of charcoal. Get a deflagrating spoon and cap : see that it is clean by heating in the Bunsen. Push the spoon down through the cap, so that it will reach to about one-third the height of the jar from the bottom. Put the charcoal on the spoon and ignite with the Bunsen ; when glowing, plunge in the jar of oxygen ; it burns brightly. When the combustion is over, remove the deflagrating spoon, pour in some lime-water, and shake up ; the lime-water becomes milky.

For the remaining experiments, two jars may be filled in the ordinary way ; another must be wiped perfectly dry and filled by downward displacement. For the next experiment obtain a deflagrating jar, *i.e.* one open at the top and bottom. Cork up the upper opening and fill with gas ; allow it to stand in the trough.

Experiment 30.—Take about four or five feet of fine iron binding wire ; make it into a spiral by winding round a test-tube, and weigh it carefully. Next fix it to the cap of a deflagrating spoon, and attach a small piece of vegetable tinder (amadou) to the lower end ; in the absence of this material, about a quarter of an inch of a wax vesta may be used. The iron wire is now ready for burning. The deflagrating jar must be removed from the trough in a proper dish, in the bottom of which a piece of writing paper has been placed, and allowed to become saturated with water. There will thus be a layer of about half an

FIG. 8.



inch of water at the bottom, then the paper, and underneath

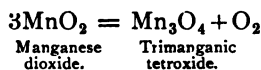
that another thin layer of water. Loosen the cork at the top, light the tinder or vesta, and immediately place the wire in the jar (Fig. 8). It burns brilliantly, throwing out a number of sparks, while from time to time drops of molten oxide fall to the bottom : these are so hot, that if allowed to come in contact with the porcelain dish they would fuse into the glaze even after falling through an inch of cold water. The writing paper momentarily arrests them, and thus gives them time to cool. When the burning is over, remove the unburnt end of wire ; collect very carefully the whole of the globules of oxide of iron, place them in a crucible or evaporating dish, and thoroughly dry them with a gentle heat. Weigh the oxide and the remainder of the iron ; there should be a sensible increase of weight over that of the iron alone previous to the burning : the increase is, of course, due to the oxygen, which is also present in the oxide.

Experiment 31.—In one of the jars of gas, collected over the trough, burn a fragment of sulphur in the deflagrating spoon ; notice the brilliant light. Add to the jar after the burning some litmus solution ; it is turned red.

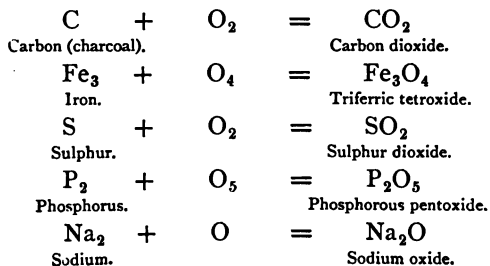
Experiment 32.—In the other jar burn a piece of phosphorus the size of a small pea, remembering first to carefully dry it. The light produced is most brilliant. Add litmus solution, and observe that again the colour becomes red.

Experiment 33.—In the dry jar a piece of metallic sodium is to be burned. Sodium has such an affinity for oxygen that it requires to be kept in a liquid which does not contain that element : naphtha is usually employed. Cut off a little piece about the size of a pea, being most careful that the knife and everything which touches the metal is *perfectly dry*. Place in a clean and *dry* deflagrating spoon ; heat in the Bunsen until it just glows, then put it in the jar of gas ; it burns brightly : the products of combustion which are solid remain in the spoon. Allow it to get quite cold, then place the spoon in a little water in a beaker, and dissolve off the oxide of sodium. To some litmus solution in a test-tube add just a drop of dilute sulphuric or nitric acid. Pour the red solution thus produced into the beaker containing oxide of sodium ; the blue colour is restored.

Another method sometimes employed for the preparation of oxygen consists of heating to redness, in a closed iron tube, the black oxide of manganese. Unless large quantities of the gas are required this method is now rarely employed : the gas is always impure from the presence of traces of chlorine, &c., from foreign substances contained in the oxide. The decomposition is thus represented :—



PROPERTIES.—Oxygen is a colourless, odourless, neutral and non-inflammable gas, which until 1877 had never been liquefied. It is slightly soluble in water, one volume of water at 15° C. dissolving about three volumes of oxygen. Among its properties, by far the most important is, that it possesses the power of supporting respiration. The gas in the pure state, however, is so active that a diluting agent is required : in the atmosphere this is supplied by the presence of nitrogen in large quantity. It also supports the combustion of inflammable bodies : substances which burn in air burn with increased brilliancy in this gas. Its chemical activity is so great that, with the exception of fluorine, it combines with all the elements. The class of bodies thus formed is an important one, to which the name of *oxides* has been given. The preceding experiments show the formation of several of these. The composition of the bodies produced is shown in the following equations :—

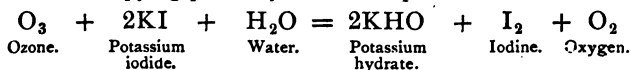


There is one important point of distinction between various oxides to which the student's attention will have been directed in the experiments already made : one group, of which sulphur dioxide is a representative, reddens a solution of litmus ; another series, represented by sodium oxide, is characterized by the property of restoring the blue colour to litmus solution which has previously been reddened. The oxides of the first group, when dissolved in water, produce *acids* ; those of the second group are known as *bases*.

OZONE (ALLOTROPIC OXYGEN).

This gas, which has never been obtained in the pure state, is a curious modification of oxygen. Its density is exactly half as much again as that of oxygen. Traces of it are found in the air near the sea-side, and in the open country. It can be formed by the passage of a series of electric sparks through either air or pure oxygen ; and may be recognised by its odour whenever an electric machine is worked. The quantity of oxygen thus changed is however very small, but if a *silent electric discharge* be passed through the gas, care being taken to avoid sparks, a much larger proportion of oxygen undergoes this transformation. In the absence of the special apparatus necessary for this experiment, ozone may be prepared by the action of phosphorus or moist air.

In properties, ozone is much more active than oxygen, converting copper and even silver into oxides. Iodide of potassium is decomposed by it, iodine being liberated and in the presence of water potassium hydrate formed. When substances are oxidised by ozone no diminution in volume of the gas takes place. The density of ozone shows that three volumes of oxygen condense to form two of ozone ; during oxidation by its agency it is the extra volume of oxygen which enters into combination, the normal oxygen set free occupying precisely the same space :—



Ozone is represented by the symbol O_3 , common oxygen being indicated by O_2 .

Free iodine combines with starch to form a deep blue coloured compound. Ozone may easily be detected by exposing paper dipped in a solution of starch and potassium iodide ; a trace is sufficient to develop a blue colour.

Experiment 34.—Carefully scrape a stick of phosphorus until quite clean, under water, then place it in a gas-bottle and cover with a plate. Put a piece of starch the size of a large shot into a test-tube and a quarter fill with water, shake up and then boil ; add a fragment of about the same size of potassium iodide and allow it to dissolve. Dip some pieces of paper in the solution, and after the phosphorus has been in the jar for about twenty minutes or half-an-hour introduce the paper ; ozone, if present, will immediately produce a blue tint. If the coloration does not at once appear, a piece of paper may be left suspended in the jar and will soon change colour.

Ozone very slowly decomposes into oxygen at ordinary temperatures. At a temperature of 237° C. the change is instantaneous ; the gas, which contracted when the ozone was first formed, once more regaining its original volume.

When an element occurs in two or more distinct forms it is said to be *allotropic* : for this reason, ozone is sometimes referred to as 'allotropic oxygen.'

Summary.

Oxygen is widely distributed. Discovered in 1774 by Priestley. May be prepared by decomposition of mercury oxide, chlorate of potash, and manganese dioxide. Manganese dioxide assists the decomposition of chlorate of potash without itself undergoing change. Forms compounds called oxides, one group of which reddens litmus ; another restores the blue colour. Properties : a colourless, odourless gas, non-inflammable, supporter of respiration and combustion, neutral to litmus solution.

Ozone is a condensed form of oxygen, has a peculiar odour, is produced in the passage of electricity through the air, also during the oxidation of moist phosphorus, is even more active

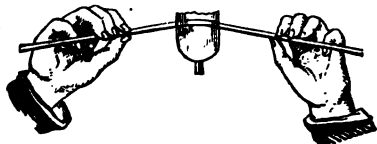
as an oxidising agent than oxygen, is decomposed by a temperature of 237° C. into oxygen.

Laboratory Hints.

The student will require the following pieces of apparatus before he proceeds with the preparation of the gases.

For generating apparatus No. 1, Fig. 7, take a test-tube three-quarters of an inch in diameter and 6 inches long. Select a cork which just fits it, after being rolled or squeezed in order to soften it. Take a piece of glass tubing 18 inches long, and bend it to shape shown in figure. The best way to bend glass tubing is to hold it horizontally in a gas flame (Fig. 9) from an ordinary burner, the long way of the flame. Keep twisting it round until it begins to soften, and then allow it to bend over to the right shape by its own weight. If this is done properly the tube will assume a long uniform curve. Next, by means of the blow-pipe, make the ends of the tube just red-hot; this will round off the sharp edges. Should it be necessary to cut the glass tubing to the proper length, this may be easily done by cutting a notch in the tubing with a triangular file, and then breaking, by a kind of combined *pull* of the glass asunder and snapping it away from the notch. Next it will be necessary to

FIG. 9.

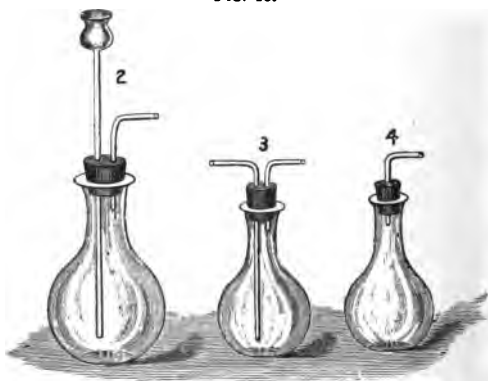


bore a hole in the cork. For this purpose instruments called cork-borers are provided: they consist of a set of thin brass tubes, the lower ends of which are sharpened. A rod is also contained in the set, in order to thrust out of the borers the pieces cut from the holes. The rod can also be pushed through two holes in the top of the borer, forming a handle to grasp when boring. Before commencing, see that the borer is clear: then, beginning at the *small* end of the cork, bore carefully by twisting the borer and pushing it through. Take care, while going on, that the hole is *straight*. Do not place the cork against the bench and bore into the wood, as this blunts the borer. The hole should be *cut*, not bruised through. When finished, thrust out the boring with the rod. The borer selected should be one just a shade less in diameter than the glass tubing. Before pushing the

glass tube into the cork it may be advantageously touched over with a little grease. Hold the glass in a duster so as to protect the hand in case it breaks. The cork and glass tube should fit perfectly air-tight; lutings and cements of all kinds are unnecessary for the preparation of such apparatus, which the student should take the trouble to make properly in the first place, as so doing will save much time and vexation in after-experiments.

This completes apparatus No. 1, which is shown in use in Fig. 7. A couple of tubes should also be made of hard or combustion tubing, which stands a much higher temperature than the other kind. Take a piece of combustion tubing a foot long,

FIG. 10.



and warm it gradually in the middle over the flame of the foot-blow-pipe, at first without blowing; keep turning it in the flame; when warm, increase the heat slowly by blowing, until at last the whole strength of the blow-pipe is applied. The glass will shortly soften, and then the two ends must be drawn asunder. Break off the connecting thread of glass close to the end of the tube; fuse up the small hole with the blow-pipe and the tube is complete, with the exception of rounding the edges of the open end in the flame, which must be done when the bottom is cool. Such tubes must be allowed to cool slowly, or else there is danger of their cracking: for the same reason they must be heated when in use very carefully and gradually.

No. 2 apparatus should now be made. Fit a good cork to

the 16 oz. flask ; take 6 inches of glass tubing and bend it in the middle at right angles, always remembering to round off the ends. Bore two holes through the cork, one to fit this and one the thistle funnel. The glass bend should be just pushed through the cork, and the funnel should reach to within a quarter of an inch of the bottom of the flask.

No. 3 apparatus consists of an 8 oz. flask, to which a cork is fitted with two holes ; through one is passed a bent tube reaching the bottom of the flask, and through the other a short bend like that in No. 2 apparatus. This same flask should also be provided with a cork with one hole and a single glass bend. The three are shown in Fig. 10.

The whole of these should be constructed at the outset : they will be found sufficient for the preparation of most of the gases. If thoroughly cleaned immediately after use, they should last through the whole course of experiments.

In the special sketches subsequently given the student may often adapt bent glass tubes already made by the use of india-rubber connections, instead of making new ones of the exact shape shown.

The terms 'leading tube' and 'delivery tube' are applied to the tube by which a gas emerges from any particular piece of apparatus.

For the collection of gases by displacement and other purposes a piece of glass tubing about 14 inches in length should be bent at right angles 3 inches from one end.

For experiments gases are usually collected in gas jars or bottles. For ordinary purposes of the student, wide-mouthed bottles do very well about the size of a common pickle-bottle ; they should however be of white glass. The gas is best retained in the bottle by placing a ground glass plate on the mouth, which must be ground flat. This is very easily and quickly performed in the following manner : Procure a piece of plate-glass about 6 or 8 inches square ; place on it some emery of medium coarseness and water. Take the bottle, hold it firmly mouth downward on the plate, and rub with a circular motion. Half a minute's rubbing will generally suffice to grind the top true. The joint between the glass plate and the bottle is rendered air-tight by smearing the plate with a little grease. The resin cerate of the druggist answers this purpose admirably.

Gases which are insoluble or only slightly soluble in water are best collected over the pneumatic trough. One of the most convenient forms of this apparatus is a circular basin of earthenware, and a little stand known as a bee-hive shelf on which the inverted jar is placed. To use the trough proceed in the following manner : Put sufficient water in the trough to cover the bee-hive shelf ; then, having ready the jars and plates, fill each jar with water, put on the plate, turn it upside down, and place the mouth of the jar under the water in the trough : on withdrawing the plate the jar remains filled from the pressure of the atmosphere. If there is room, all the jars should in this way be placed in the trough. Next place the leading tube from the generating apparatus under the shelf, and when the gas has driven the air out of the apparatus, begin to collect by placing one of the bottles on the shelf. Have ready its plate ; when it is full, remove it and substitute another, taking care to keep their mouths under the surface of the water during the whole operation. Next close the mouth of the full bottle with a plate, and take it out of the trough. Fig. 7 shows a jar placed for the collection of gas, the front of the trough being removed in order to show the bee-hive shelf.

Gases which are soluble in water must be collected another way. They are sometimes collected in a pneumatic trough over mercury. In general, however, the process of displacement is used. In this operation the gas is poured into the bottle and drives the air out. In cases where the gas is heavier than air, stand the bottles upright, and let the leading tube from the generating apparatus reach to the bottom of the bottle. Cover the top with a piece of cardboard, in order to prevent the escape of gas by diffusion. In order to find out if the bottle is full, test from time to time near the mouth. The test employed must depend on the nature of the gas ; oxygen may be recognised by its power of igniting a glowing splinter. When full close with a plate.

When the gas is lighter than air the whole arrangement must be inverted : the gas is then said to be collected by upward displacement.

CHAPTER VI.

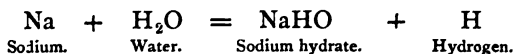
HYDROGEN.

Symbol, H. Atomic weight, 1. Density, 1. Specific gravity, 0.0691. Molecular weight, H₂, 2. Molecular volume, \square .

OCCURRENCE.—Hydrogen is chiefly found in combination with oxygen in the form of water, which contains one-ninth of its weight of hydrogen ; it is also a constituent of certain stars and nebulae. The attraction of the metal sodium for oxygen is so great that it readily decomposes water, setting free the hydrogen, which, with sufficient care, can be collected.

PREPARATION.—*Experiment 35.*—Drop a very small piece of sodium into a trough of water ; notice that it melts, and rushing round on the surface for some time, becomes smaller, and finally disappears. If the globule of metal is held under the surface, bubbles of gas are seen to arise. To collect these, proceed in the following manner : Cut a piece of sodium the size of a pea, wrap it up carefully in fine wire gauze, doubling it over, so that there is not the slightest chance of the sodium escaping when melted. Have in the trough a small stout glass jar inverted and full of water, ready for collecting the gas ; be sure that not a bubble of air remains in it. Throw the sodium and gauze in the water and collect the escaping gas. Apply a light, it burns with a pale flame tinged yellow by the sodium vapour.

The chemical change is thus represented :—



The combination of sodium and oxygen, even under these circumstances, is accompanied by considerable heat which at

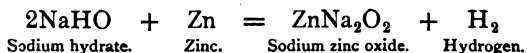
times inflames the hydrogen. If in any of these experiments with sodium and water the escaping gas should take fire, stand some little distance until it has burnt out, and then wait until the molten sodium hydrate, which at first floats on the surface of the water, is dissolved : at this moment there is always a slight spit, and there is the danger, if a person is standing immediately over it, that portions of the hydrate may get into the eye. It would be wiser for the student to omit these experiments until he has first seen them performed by the teacher.

Take another fragment of sodium and dissolve in a small quantity of water in the evaporating basin ; when the action is over, observe the soapy feel which the liquid gives to the fingers : this is a characteristic of the class of bodies of which sodium hydrate is a member. Evaporate to dryness, and notice that a white solid substance remains.

Sodium hydrate is frequently called caustic soda, or soda only, for the sake of brevity. The formula of sodium hydrate shows that it contains hydrogen. By the action of zinc this may also be obtained.

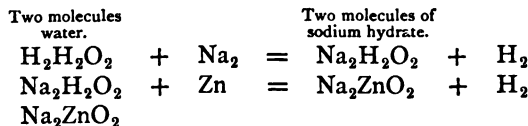
Experiment 36.—Fit a four-ounce flask with cork and single delivery tube ; put in a small quantity of zinc and a piece of solid sodium hydrate about the size of a hazel-nut ; add just sufficient water to cover the bottom of the flask. Fix in the retort stand and apply heat ; at first bubbles of air come over, but when the sodium hydrate is melted, hydrogen is evolved and may be collected over the pneumatic trough. The water takes no part in the chemical action, but is simply added to prevent the heat cracking the flask.

The following is the re-action which occurs :—



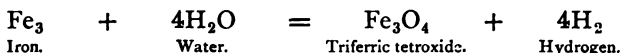
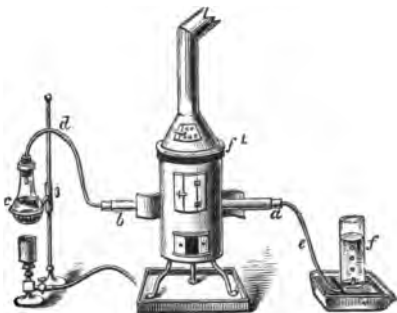
The most interesting point about these two experiments is, that by means of them we succeed in obtaining hydrogen from water in two distinct instalments ; proving that at least two atoms of hydrogen are present in the molecule of water. The successive displacements of hydrogen from water may

be shown more clearly by writing the equation in the following manner :—



There are several other metals beside sodium which are able to decompose water ; some of them, however, require a higher temperature. Iron is one of these metals. The decomposition is most readily effected by taking an iron tube about an inch in diameter, filling it with loose iron turnings, and heating to redness in a furnace. A flask *c* is used for the generation of steam ; it is attached by means of glass and india-rubber tubes and corks *d* to the iron tube *b*. The steam which enters *b* is decomposed ; hydrogen escapes, and is collected in the jar *f*. The change is thus represented :—

FIG. 11.



The oxide of iron, Fe_3O_4 , produced in this experiment, is magnetic, and, unlike the oxide developed on iron by exposure to the atmosphere (Fe_2O_3), is *adherent*, and a protective from further rust. Barff's process for preventing articles from rusting is an application of this principle.

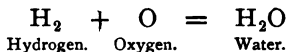
The most convenient method for preparing hydrogen consists of acting on either zinc or iron with dilute hydro-

chloric or sulphuric acid. As a rule zinc and sulphuric acid are employed. The gas comes off readily and at the ordinary temperature.

Experiment 37.—Place about half an ounce of granulated zinc in the flask of No. 2 apparatus ; to the delivery tube attach the bent glass tube of the apparatus No. 1 by means of a piece of india-rubber tubing, and arrange for the collection of the gas with the pneumatic trough. Pour about four ounces of water in the flask through the thistle funnel. Next add a very little concentrated commercial sulphuric acid ; about a tea-spoonful is sufficient. Give the flask a shake ; immediately there is a brisk effervescence, and the gas may be readily collected over the trough. More sulphuric acid should be added as the action slackens. Apply a light to the first jar that comes over ; it detonates somewhat violently, from the fact that it contains a mixture of hydrogen and air, which is explosive. The second may very possibly also contain air ; the third jar will probably be filled with pure hydrogen. Collect now four jars for experiment.

PROPERTIES.—*Experiment 38.*—Hold a jar of gas mouth downward ; apply a light : the gas burns at the mouth with a non-luminous and almost colourless flame. Thrust the taper up into the jar ; the taper is extinguished, but the gas continues to burn.

The combustion of hydrogen in oxygen or atmospheric air produces water :—

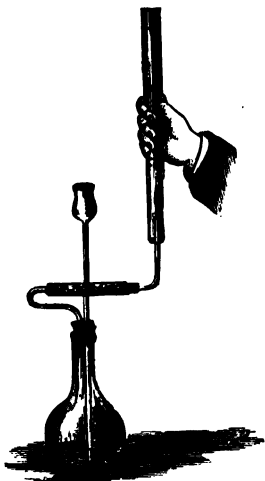


All gases evolved from mixtures, in which water is present, contain aqueous vapour ; therefore, before attempting to prove the presence of water as a result of the combustion of hydrogen, we should first *dry* the hydrogen itself. This is easily effected by passing the gas over some substance which has an attraction for water : the most important desiccating or drying agents used by the chemist are calcium chloride, sulphuric acid, and quicklime. Which-ever of these is selected must depend on the nature and

properties of the gas to be dried. Hydrogen may be dried by the use of either calcium chloride or sulphuric acid.

Experiment 39.—Select a piece of glass tubing of half an inch or five-eighths bore and about nine inches long, round off the ends with the blow-pipe, and fit a cork to each. To the one cork fit a tube bent at right angles, with the end drawn out to a jet ; through the other pass a piece of tubing bent to the shape shown in Fig. 12 ; or simply fit to it a straight piece of glass tube, and connect to the leading tube of the generating flask with india-rubber tubing ; this part of the apparatus would then have to be supported by the retort stand. Fill the large tube with small fragments of calcium chloride, and place at each end, between the chloride and the cork, a plug of cotton-wool. A slow current of gas passed through this apparatus will emerge in the dry state. If necessary, place some more zinc and sulphuric acid in the generating flask ; let the gas escape until a jar collected burns quietly without explosion ; then attach the drying tube, and after a few seconds, light the gas as it issues from the jet. *Too much stress cannot be laid on this injunction, to FIRST see BEFORE lighting the jet that a collected jar of the gas burns quietly. Want of attention to this direction will lead to EXPLOSION of the whole apparatus.* Take a glass tube eighteen inches or two feet long, and about half an inch diameter ; if necessary dry the inside by pushing a plug of cotton-wool through ; hold it over the jet : the watery vapour condenses in the cooler parts of the tube.

FIG. 12.



This experiment is often accompanied by a peculiar musical note produced by a rapid series of small explosions within the long tube. The moisture which condenses on a

kettle or other vessel of cold water heated over a gas stove, is the product of combustion of the hydrogen of the coal gas.

Hydrogen is the lightest substance known, and for this reason is conveniently chosen as the standard for comparison of other gases ; its buoyancy has led it to be used for the purpose of filling balloons ; coal gas, from its greater cheapness, is, however, usually preferred. The following experiments are illustrative of this property.

Experiment 40.—Take a jar of the gas, and setting it down mouth upwards, take off the glass cover ; after the expiration of thirty seconds apply a light : the gas will be found to have entirely escaped. Take a second jar, and holding it mouth downwards, remove the glass plate ; let it also remain for thirty seconds and apply a light : the gas will take fire and burn as usual, but little of it having escaped.

From its great lightness this gas may be poured upward from jar to jar. Take an empty jar, invert it, and removing the plate from a full one, pour the gas *up* into it. In ten seconds place a light to each jar : the gas in the inverted one will burn, the other will be found to contain no hydrogen.

The properties of this gas as deduced from experiment are that it is colourless, odourless, tasteless, inflammable, a non-supporter of combustion and of very low density. The gas prepared from zinc and sulphuric acid has generally a slight odour from the presence of impurities in the zinc and acid ; when the gas is required in a state of absolute purity, this is ensured by the use of pure re-agents. Should iron be used instead of zinc for its production, the smell is much stronger, through the presence of compounds of hydrogen with carbon ; carbon being an invariable constituent of common iron. The gas is not poisonous, but animals placed in it soon die from simple deprivation of oxygen. It is very slightly soluble in water, 100 volumes dissolving only 1·93 volumes of the gas.

It will be remembered by the student that hydrogen, in common with oxygen, is one of the gases which were

recently liquefied by MM. Cailletet and Pictet. Hydrogen was even obtained in the solid form, appearing as a jet of solid steel-blue particles. In many of its chemical relationships it behaves rather as a metal than a non-metal ; its appearance in the solid state tends to confirm this view.

Summary.

Hydrogen is principally found in water. May be prepared by the action of metals on that liquid, as sodium, iron, &c. ; also by action of zinc or iron on various acids.

Hydrogen is a colourless, odourless and tasteless gas, inflammable, a non-supporter of combustion : it is also neutral to litmus solution.

Laboratory Hints.

It must not be forgotten in dealing with sodium that the fingers must be perfectly dry.

In collecting hydrogen from sodium hydrate and zinc, if the neck of the flask has been touched with the soda, there is frequently difficulty in keeping the cork in from its consequent soapiness. This may generally be prevented by just touching round the cork with dilute sulphuric acid.

Great care must be taken in mixing sulphuric acid and water ; if the directions given are followed, there need be no fear ; on no account add the water to the sulphuric acid.

Never omit the precautionary measures given before lighting a jet of hydrogen.

In handling chloride of calcium, place it in the drying tube as quickly as possible, and *immediately* replace the cork in the jar containing it.

CHAPTER VII.

OXIDES OF HYDROGEN.

THERE are two oxides of hydrogen known :—

Hydrogen mon-oxide, or water . . . H_2O .

Hydrogen dioxide, or hydroxyl . . . H_2O_2 .

WATER.

Formula, H_2O . Molecular weight, 17.96. Density, 8.98. Specific gravity as steam, 0.622.

OCCURRENCE.—Water is found so largely distributed in nature, and its uses are so well known, that a description of its occurrence and many of its properties is superfluous. It is found in the three distinct forms of ice, water, and steam.

PROPERTIES.—There are very few substances which are not more or less soluble in it, hence we never find water in a state of purity in nature. Even rain water contains traces of gaseous bodies dissolved from the atmosphere, while river and spring water hold a considerable quantity of saline matters in solution.

Experiment 41.—Evaporate to dryness on a clean piece of platinum foil a few drops of common water; notice that a perceptible residue remains; contrast with that obtained from distilled water.

The method of purification of water by the process of distillation has been already referred to (p. 18).

Experiment 42.—Take an eight-ounce flask fitted with cork and single bent tube, as shown in Fig. 10; attach with india-rubber a glass tube, leading into the pneumatic trough; fill the flask to overflowing with cold spring or rain water; push in the cork; the water displaced will drive the air from out the leading tube. Heat the water with the Bunsen, and place a large test tube to collect in the ordinary manner the gas which is evolved; let the water boil until no more gas is disengaged.

In this way an estimate may be made of the quantity of air, and other gases, the water, when cold, held in solution. This quantity, though small, is of great importance, being the supply from which fishes derive the oxygen necessary for the support of respiration. The experiment also shows that gaseous impurities are not separated from water by distillation, being carried over by the steam.

The study of the effects of heat on water belongs rather to the domain of physics than chemistry, but it is important that the chemical student should know the principal changes produced by heat.

In common with other bodies water is expanded by the action of heat: this is readily observed in the following experiment.

Experiment 43.—Fill an eight-ounce flask with cold water to within one inch of the mouth; apply heat, and notice that before the boiling point is reached the water expands until the flask is entirely filled; set aside to cool, or cool more rapidly by placing the flask in a trough of cold water; notice that the original volume is regained.

If a piece of ice be taken at a temperature considerably below the freezing point, and subjected to heat, an interesting series of changes may be observed. The ice first expands as heat is applied; at 0° C. the temperature remains stationary until the whole of the ice is melted. The heat necessary to melt a given weight of ice at 0° C. would raise the same weight of water from 0° to 79° C. A considerable diminution of volume accompanies the change of ice into water, 10.9 volumes of ice producing only 10 volumes of water. The whole of the ice being melted, a further application of heat raises the temperature steadily until 100° C. is attained. At first the ice-cold water *contracts* as it becomes hotter, until 4° C. is reached. At this point water expands on being either heated or cooled; this temperature is therefore termed that of the *maximum density* of water, as at this point the greatest weight of water is contained in the smallest space, maximum density being necessarily associated with *minimum* volume. The expansion proceeds regularly until 100° C.; at this temperature the water boils, and is entirely changed into the gaseous state by a continued application of heat. The temperature remains constant while any water is left. The quantity of heat necessary to convert a given weight of water at 100° C. into steam at the same

54. *Text-Book of Inorganic Chemistry.*

temperature is sufficient to raise 537·2 times the weight through 1° C.

Water gives off, at all temperatures, vapour which exerts a definite pressure ; as the temperature rises the pressure of the vapour also increases. At the boiling point of water, or any liquid, the pressure or *tension* of its vapour is equal to that of the atmosphere. This fact may be easily proved by experiment.

Experiment 44.—Take a U tube A, as shown in Fig. 13, with

FIG. 13.



one end sealed ; the limbs of the tube may be from about one foot to eighteen inches long and three-eighths of an inch diameter. Pour in a few drops of water, and let them run round to the sealed end ; next fill with mercury, so that the metal shall stand at the bottom of the straight portion of the open limb of the tube, the closed one being full ; the mercury is retained in position when the tube is upright by the pressure of the atmosphere ; on its surface in the sealed end a few drops of water will be seen floating. The sealed limb must now be

enclosed in a jacket (B) composed of a glass tube sufficiently wide (about one inch diameter) to permit of the passage of steam between the two glass tubes. Fit the steam jacket with two corks ; fix a glass bend to the upper one ; and through the lower bore one hole in the centre for the U tube, and another in which must be introduced a glass tube to lead away the waste steam. Fix the apparatus upright in the retort stand, and pass steam through the jacket from water boiled in a flask ; as the temperature of the jacket rises, the mercury is depressed, until it at last is stationary, and at a level in the two limbs of the U tube.

The mercury in the outer limb is subjected to the pressure of the atmosphere, that in the inner to the pressure of the steam ; the surfaces being level with each other is a proof that the two pressures balance, and therefore the boiling point of a liquid is that at which the tension of its vapour equals that of the atmosphere.

It follows that if the pressure on a liquid be varied, its boiling point also changes ; if a few drops of water be placed in the vacuum at the top of the mercurial column of the barometer, where the pressure is *nil*, the boiling point falls below that at which water freezes. On the tops of mountains, where the atmospheric pressure is comparatively low, water boils below 100° , while in steam boilers, where it is exposed to great pressure, the boiling point rises to 144° with a steam pressure of 60 lbs. to the square inch (4 atmospheres), and to 180° at a pressure of 150 lbs.

Steam in cooling passes through a series of changes which are just the converse of those it experiences on being heated ; it gives out just the same quantity of heat in changing from steam to water as was required to convert the water into steam ; further, the water in solidifying evolves the same amount of heat as was necessary to effect its liquefaction.

The fact has already been mentioned that water acts as a solvent of very many substances ; it usually so acts more powerfully when hot ; but gases are more readily absorbed

by cold water. Thus sodium sulphate is soluble in rather more than double its weight of water at usual temperatures ; whereas the salt may be dissolved without difficulty in its own weight of warm water.

Experiment 45.—Take half an ounce of sodium sulphate, place in a test tube, and add the same weight of water ; heat gently : the salt is dissolved. Now allow the solution to cool ; as the temperature falls, the water is unable to hold the whole of the salt in solution, and a portion separates in the solid state, as a series of long four-sided prisms : these are *crystals* of sodium sulphate.

A substance is said to be crystallized whenever it assumes a definite geometric form ; the same substance, as a rule, always crystallizes in the same form or group of closely allied forms. When a body assumes two distinct crystalline forms, it is said to be *dimorphous* : the study of even the more familiar elements includes some very important instances of dimorphism. A body which does not occur in crystals is termed *amorphous*, i.e. without (crystalline) form.

Many bodies require, in order to build up their crystals, a certain quantity of water ; on removing this, the crystalline form is destroyed.

Experiment 46.—Pour the contents of the tube from the last experiment on a filter, so that the liquid may drain off (mother-liquor) ; dry the crystals by gently pressing them between the folds of a dry filter. Remove the dry crystals into a test-tube which is also dry, and very gently apply heat ; the crystals melt, a quantity of water is given off, which condenses in the upper part of the tube, and ultimately a white, solid and amorphous mass remains at the bottom.

Such water is called *water of crystallization*, and is always constant in quantity. Thus, crystallized sodium sulphate contains 10 molecules of water to one of the salt ; this is represented in the formula $\text{—Na}_2\text{SO}_4, 10\text{H}_2\text{O}$.

COMPOSITION.—Water, until within the last hundred years, was looked on as an element. The experiments

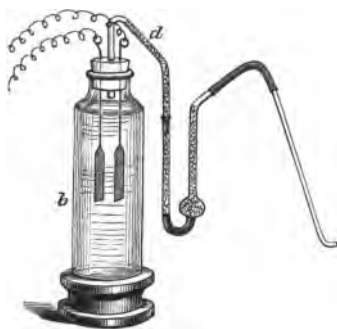
described in the last chapter on hydrogen will have shown the student that its composition is compound: hydrogen having been obtained from it, and water again produced by the combustion of that gas in air.

By intense heat water may be separated into oxygen and hydrogen; the most convenient force to apply for this purpose, however, is that of voltaic electricity. The following series of experiments on the analysis of water by electricity (electrolysis) and its synthesis, should, if possible, be performed by the student; failing this, he should read the directions here given most carefully, and watch the results obtained when the experiments are performed by the teacher.

Experiment 47.—The electrolytic apparatus, shown in Fig. 14, is to be attached by

FIG. 14.

means of the wires to a battery consisting of two or three Grove's or Bunsen's cells. Such an apparatus is readily constructed by taking a wide-mouthed bottle of six or eight ounces capacity, fitting it with a good cork, passing through it the delivery tube *d* and two platinum wires, to which pieces of platinum foil are attached; the bottle, being filled to the neck with water,



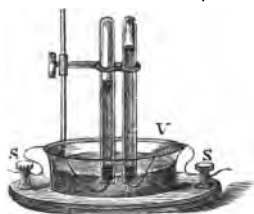
to which twenty or thirty drops of sulphuric acid have been added, is ready for use. Instead of the platinum wires through the cork as shown in the figure, pieces of glass quill tubing may be used, the platinum wires being fused into the ends of the tubes, which are to be filled with mercury; the connection with the battery is then easily made by pushing the *clean* ends of the wires into the mercury. The leading tube *d* has a drying tube filled with chloride of calcium attached to it; unless the issuing gas is required to be perfectly dry, this may be dispensed with. The apparatus being in working order, connect the battery: notice that

a stream of bubbles of gas ascends from each piece of platinum. Collect the gas issuing from the leading tube in an egg-shaped soda-water bottle over the pneumatic trough. When full, close the mouth either with a cork or the palm of the hand ; wrap up the bottle carefully in a duster and apply a light, the gas explodes violently.

The pieces of platinum foil are called *electrodes* ; that connected with the zinc of the battery is the *negative*, the other the *positive* electrode.

Experiment 48.—Proceed again to electrolyse water, using this time an apparatus (Fig. 15) in which the gas evolved from each electrode is collected separately. Fill the vessel *v* with acidulated water, then fill the glass tubes with the same

FIG. 15.



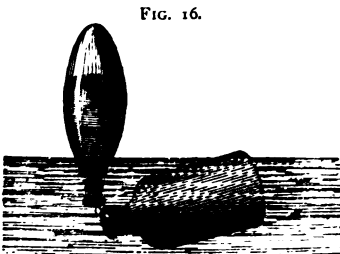
water, and invert one over each electrode. Connect the battery wires to the binding screws *SS*, to which the electrodes are attached. Gas immediately rises in each of the tubes ; it is soon noticed that in that inverted over the negative electrode the volume is double that evolved from the positive electrode. When nearly full remove the inverted tube

containing the larger quantity of gas, and apply a light ; it burns quietly with the familiar pale blue flame of hydrogen. In the second tube of gas plunge a glowing splinter ; it re-lights, the gas being oxygen.

These experiments prove that water is capable of decomposition into oxygen and hydrogen. The student should also learn that the reunion of oxygen and hydrogen again produces water.

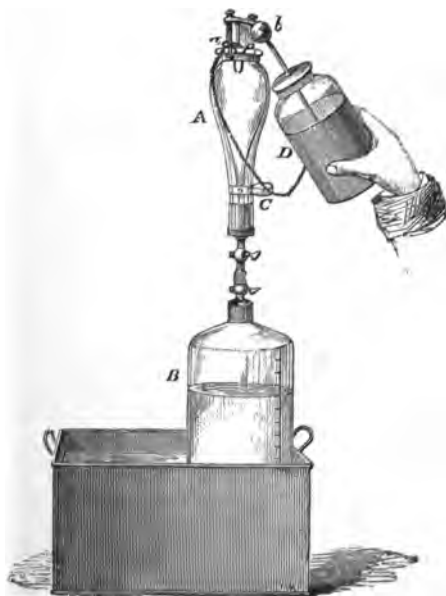
Experiment 49.—Take the soda-water bottle used for the collection of the mixed gases in the electrolysis of water ; fill it with water, and pour out into a graduated measure ; pour in again one-third of the quantity it holds, and mark the height by a file on the outside of the bottle ; pour in another third, and again make a mark. Now place the bottle in the trough, fill with water, and pour in, from a jar previously filled, one-third its volume of oxygen (Fig. 16). An easier way is to place the

soda-water bottle on the bee-hive shelf, and place the mouth of the other underneath it; or a funnel may be inverted in the mouth of the soda-water bottle. Next fill the remaining two-thirds of the bottle in the same way with hydrogen. Remove the bottle, give it one or two shakes, and after wrapping in a duster or towel, apply a light: it explodes in just the same manner as the detonating gas collected by electrolysis.



The recombination of the two gases may be also effected

FIG. 17.



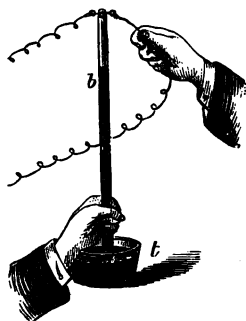
by passing an electric spark through the mixture. Cavendish

used in his investigations a strong glass vessel with two platinum wires inserted in it so that the electric spark might pass through the gases between their ends. A form of his apparatus is shown in A, Fig. 17. This vessel is first exhausted by the air-pump, then attached to the graduated glass jar containing a mixture of two volumes of hydrogen and one of oxygen ; on opening the stop-cock C, the vessels fill with the mixture ; the stop-cock is closed and an electric spark passed ; drops of water condense on the sides of the vessel. The stop-cocks may be again opened and the vessel re-fills ; by the passage of a spark a second quantity of water is produced. This operation may be repeated until the whole of the gases have been caused to combine ; by this time there is an appreciable quantity of water in the glass vessel.

A somewhat similar experiment to this, but performed on a smaller scale, may be tried by the student himself.

Experiment 50.—For this experiment procure a *eudiometer tube* (Fig. 18). This consists of a stout glass tube about twenty

FIG. 18.



inches in length and half an inch diameter, closed at one end. Near the closed end two platinum wires are fused into the glass, their points being about a sixteenth or eighth of an inch apart. Fill this tube with mercury, and invert in a small trough also containing mercury, and provided with an india-rubber pad at the bottom. Fill the tube about one-third full of the mixed gases evolved by the apparatus in Fig. 14; attach the wires to a small induction coil or an electrophorus ; hold

the eudiometer down firmly on the rubber pad, and pass a spark through the gaseous mixture ; there is a bright flash of light at the moment of combination ; lift the tube slightly, the mercury rushes in and entirely fills it.

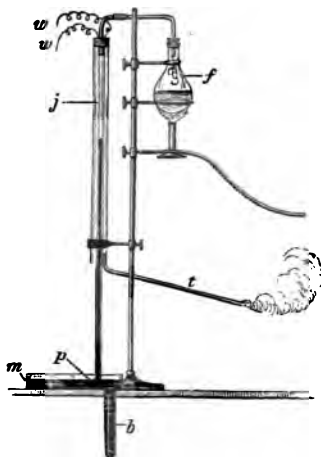
In this experiment the water vapour first formed imme-

diately condenses. Another most important experiment, which the student should perform, if possible, consists of measuring the relative volume of the mixed gases, and the steam produced by their union.

The apparatus, usually described for this experiment, necessitates the use of means for maintaining the temperature of the eudiometer well above the boiling point of water. Vapour of amyl alcohol, which boils at 132°C. , is passed through an outer tube in which the eudiometer is placed. There is an elegant modification of this apparatus devised by Professor Reynolds, in which use is made of the fact that water boils at a lower temperature under less atmospheric pressure. The pressure on the water vapour inside the eudiometer being lessened, it is kept above its condensing temperature simply by the passage of steam through the outer tube.

Experiment 51.—Take a eudiometer tube about thirty inches long; place over it the jacket *j*, which should be about fifteen inches in length and an inch in diameter. Each end of the jacket is fitted with a cork; through the upper one a bent glass tube is passed, which is connected with the glass flask *f*, containing water heated by the Bunsen; *ww* are the wires, also passed through it, connecting the eudiometer with the induction coil. The lower cork has one hole which fits the eudiometer; through a second the tube *t* is fixed for waste steam. Two small india-rubber rings should be passed over the outer jacket. Fill the eudiometer with mercury and invert it in a mercury trough with india-rubber pad *p* and a well *b*. Pass into it some

FIG. 19.

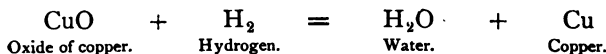


of the electrolytic gases, about sufficient to one-third fill the tube; do not let the quantity exceed this. Connect the flask *f* and pass a current of steam until the gases inside the eudiometer, expanding with the increased temperature, once more attain a constant volume. Mark this point by sliding the lower of the india-rubber rings to the surface of the mercury. Measure also and note the height of the mercury above the surface of that in the trough. Pass an electric spark, holding the eudiometer meanwhile firmly on the india-rubber pad; the gas after combination is seen to decrease in volume; as soon as stationary, depress the eudiometer in the well *b* until the mercury stands again the same height above the surface in the trough as when previously measured. Now place the second ring coincident with the surface of the mercury in the eudiometer. The amount of contraction thus measured will be found to be just one-third of the whole volume.

The current of steam must be maintained during the whole of the experiment. It may be found convenient to regulate the pressure by raising the mercury trough instead of lowering the endiometer.

Three volumes of the mixed gases have produced two volumes of steam measured at the same temperature and pressure.

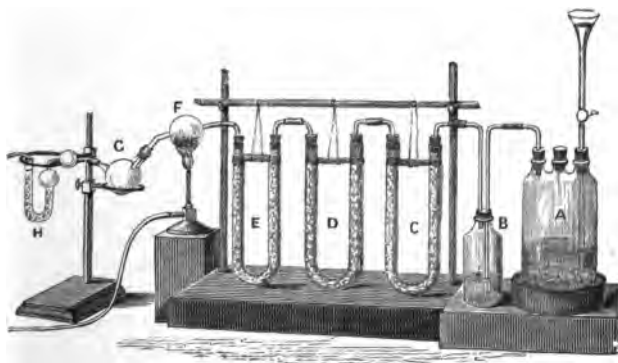
This series of experiments will have shown the student the composition of water by volume; it is necessary that he should also be acquainted with the means employed for the determination of the exact composition by weight. While iron and other metals decompose water, owing to their great attraction for oxygen, there is another group the oxides of which are decomposed by hydrogen, from their having a less powerful attraction or 'affinity' for oxygen than hydrogen has for that element. If the oxide of copper be heated in a current of hydrogen, water is produced and copper liberated in the free state:—



With proper precautions this reaction enables us to

ascertain with exactness the relative weight of hydrogen and oxygen which water contains. Fig. 20 is an illustration of the apparatus employed. Hydrogen is disengaged in the bottle A from zinc and sulphuric acid ; a solution of potash placed in the bottle B retains any traces of sulphuric acid carried mechanically over ; the tubes C, E are filled respectively with fragments of pumice moistened with mercuric chloride (HgCl_2) and strong sulphuric acid. D contains

FIG. 20.



fragments of fused potash. The passage of the gas through this series of tubes removes all traces of impurities, *dry* hydrogen only escaping from E. The globe F is made of difficultly fusible glass, and contains a quantity of dry oxide of copper. F and its contents are accurately weighed. G is a receiver arranged to receive water, while H is a drying tube filled with pumice moistened with sulphuric acid ; both G and H are also weighed previous to the experiment. Hydrogen is passed through the apparatus until the whole of the air is expelled ; then the oxide of copper is heated by the Bunsen under F ; the formation of water commences, which collects in the receiver G, the traces of vapour being retained in H. After some time, the Bunsen is removed,

the hydrogen apparatus A disconnected, and air drawn through the tubes to displace the hydrogen. The copper oxide globe is re-weighed ; the loss represents the oxygen which has combined with hydrogen to form water. The increase in weight of G and H is the weight of water which has been produced.

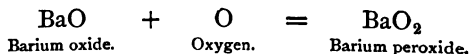
Supposing as the result of an actual experiment that the oxide of copper has lost 16 decigrammes of oxygen, the receiver and drying tube will be found to have gained 18 decigrammes in weight. We know, therefore, that water contains (very nearly) 16 parts by weight of oxygen and 2 parts by weight of hydrogen in 18 parts of water.

HYDROGEN DIOXIDE, OR HYDROXYL.

This second compound of hydrogen and oxygen differs from water in that it contains an extra atom of oxygen in the molecule ; the second atom is, however, held somewhat loosely, hence this body is readily decomposed into water and free oxygen.

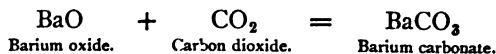
OCCURRENCE.—Minute traces of this body appear to exist in the air ; in the various processes used for the preparation of ozone, hydroxyl is also formed in small quantities.

PREPARATION.—The oxide of barium, a substance somewhat resembling quicklime, and having the composition BaO, on being heated to dull redness in oxygen, acquires another atom of oxygen and becomes BaO₂, barium peroxide :—

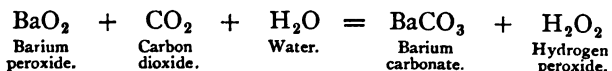


This extra atom of oxygen in the peroxide of barium, occupies a similar position to that in hydroxyl ; both these substances are unstable, the normal oxides being respectively barium oxide (BaO) and water. If a gas known as carbon

dioxide is passed through water in which oxide of barium is suspended, the following change takes place :—



But if barium peroxide be used instead, the result is different : barium carbonate is still formed, but it is evident that there is a surplus atom of oxygen. This, at the moment of liberation, combines with the water to form hydrogen peroxide :—

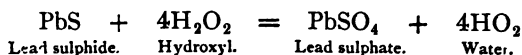


The liquid thus obtained is a dilute solution of hydrogen peroxide in water ; the barium carbonate is separated by filtration.

Experiment 52.—Prepare an apparatus for the generation of carbon dioxide gas according to directions given in Chap. XIV. Place a small quantity of barium peroxide in the mortar, and grind into a paste with some water ; pour this into a beaker, and add some ice-cold water ; a fragment of ice may be kept in the water with advantage ; pass a current of carbon dioxide for some minutes ; filter off the precipitated carbonate, and test the filtrate for hydric peroxide in the following manner : Pour a portion into a test-tube ; add sufficient ether to form a layer of about one quarter of an inch, and a few drops of potassium bichromate solution : the ether assumes a blue tint.

Dip some unsized paper into a solution of lead acetate ; let this dry, and either expose the paper to gaseous sulphuretted hydrogen or wash with a solution of that gas in water ; by this means a coating of black sulphide of lead is formed on the paper, which should be again dried. Paint this paper with some hydroxyl ; after a few seconds the colour is perceptibly lighter, while if the hydroxyl solution is sufficiently strong, the colour is perfectly discharged.

The lead sulphide has been oxidised into lead sulphate, which is white :—



The two tests given are convenient ones for the recognition of hydroxyl.

The liquid, obtained in the above experiment, may be concentrated by spontaneous evaporation in the receiver of an air-pump over sulphuric acid ; the water evaporates, leaving the less volatile hydroxyl behind.

PROPERTIES.—When thus concentrated, hydroxyl is a sirupy colourless liquid, having no odour, but a peculiar metallic taste. A slight elevation of temperature is sufficient to effect its decomposition, oxygen being evolved at even a temperature of 20° C. Its solution in water, with which it mixes in all proportions, is less easily decomposed, but even when dilute, the oxygen is easily driven off by heat. The presence of a small quantity of hydrochloric acid renders the liquid more stable, while the addition of caustic soda favours the evolution of oxygen. For further experiments it will be more convenient to use a moderately strong solution, as obtained from the chemist.

Experiment 53.—Take a *small* test-tube and fit a cork and leading tube to it ; almost fill it with hydroxyl solution ; add a few drops of a solution of sodium hydrate. Having first filled the leading tube with water, cork the test-tube, invert a small test-tube in the pneumatic trough for the collection of the gas, and apply heat to the hydroxyl most carefully. Gas is evolved : when the first test-tube is full, collect another. Test each for oxygen by means of a glowing splinter.

The experiment with lead sulphide paper shows the oxidising powers of this substance. Among other uses to which it has been put, is the renovation of old pictures.

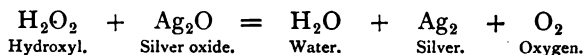
The basis of most oil colours is carbonate of lead. This salt, like the acetate, is blackened by sulphuretted hydrogen ; and as that gas is present in small quantities in rooms where coal gas is used, and is a constituent of sewer gas, in time the lead carbonate is discoloured, through the change into sulphide. Treatment with hydroxyl restores the colour by

the conversion of the sulphide into the sulphate, as in a former experiment.

Experiment 54.—Take some pieces of board which have been painted with white-lead paint and afterward exposed to the atmosphere of a chemical laboratory for some time (a week); they will have become black; or the boards may be artificially blackened by washing with sulphuretted hydrogen solution. Wash the blackened paint with the strong solution of hydroxyl: the white colour is restored.

Hydroxyl bleaches a solution of litmus, and other organic colouring matters; it is frequently used as a hair-dye for producing the washed-out flaxen tint affected by certain votaries of fashion.

From its oxidising powers, hydroxyl is reduced by many bodies which have an affinity for oxygen; it is also decomposed by certain substances which themselves do not undergo change; among these may be mentioned manganese dioxide and finely divided gold, silver, and platinum. The most remarkable class of decompositions, however, is that in which not only the hydroxyl is reduced, but also the other body, free oxygen being evolved. On adding oxide of silver to hydroxyl, the following change takes place:—



It may be as well to explain that an *oxidising* agent is one which imparts oxygen to a body, or otherwise causes it to combine with the substance. The term *oxidising* agent is also sometimes used in a looser and more general sense. Oxygen, chlorine, bromine, chlorate of potash, nitric acid, hydroxyl, &c., are examples of oxidising agents.

A *reducing* agent is one which removes oxygen or elements similar to it from compounds; the word is most frequently used to signify a substance which enables us to obtain a metal in the free state from any of its combinations. Hydrogen is the typical reducing agent; an

instance of its possession of this property is the reduction of oxide of copper to the metallic state in the experimental determination of the composition by weight of water. Carbon, sodium carbonate, sulphurous acid, etc., are also reducing agents.

Experiment 55.—To a few drops of solution of nitrate of silver, add, in a test-tube, an excess of sodium hydrate solution : a brown precipitate of oxide of silver is formed, which rapidly falls to the bottom. Wash two or three times by decantation ; pour on it some hydroxyl, and close the tube loosely with the thumb : rapid effervescence ensues. When the action is over, test the gas in the tube for oxygen by a glowing splinter.

This experiment has an important theoretical value, which will subsequently be explained.

Summary.

WATER is a widely distributed liquid ; from its solvent powers it is never found pure. Heat changes its condition from solid to liquid and liquid to gas. The boiling point depends on pressure. Many crystals contain water as an essential constituent. Is decomposed by electricity into an explosive mixture of gases ; each may be collected separately ; the gases re-combine to again form water. By volume water consists of two volumes of hydrogen and one oxygen, which condense on union to form two volumes of steam. By weight water contains sixteen parts of oxygen to two of hydrogen.

HYDROXYL is a higher oxide of hydrogen ; the second atom of oxygen is in unstable combination. Prepared by passing carbon dioxide through water in which barium peroxide is suspended. Recognised by action on potassium bichromate and also on lead sulphide. Is a sirupy liquid, powerful bleaching and oxidising agent ; colourless, odourless ; has a peculiar metallic taste. Decomposed into water and oxygen by a slight elevation of temperature. Action on lead sulphide has caused hydroxyl to be used for cleaning oil paintings. Reduced by finely divided metals, as gold ; also by oxide of silver with simultaneous reduction of the silver oxide.

Definitions and explanations of oxidising and reducing action.

Laboratory Hints.

- The U tube with jacket and eudiometer for the experiments of this chapter may be obtained from the general apparatus of the laboratory. The boiling flask shown in Fig. 13 is fitted with a safety tube F, which provides for the exit of steam until required to pass through the apparatus. The beaker D is nearly filled with water. When the screw-tap E is closed the steam must perforce adopt that way of escape ; but if the tap be opened the steam passes through the apparatus in preference to forcing itself through some four or five inches of water in the beaker. This device may be dispensed with in this particular experiment, but frequently is of great use where a current of steam is required to be carefully regulated or alternately shut off and re-admitted.

In working with mercury, take care that none is lost. Failing a proper bench with a ledge round it, it is better to stand the whole apparatus in a shallow drawer or tray. Dirty mercury may be cleaned by folding a piece of writing paper as a filter and placing it in a funnel. Prick two or three holes with a pin through the bottom ; pour in the mercury : it runs through perfectly bright and clean. To fill a U tube, pour in as much mercury as it will hold ; then close the open end with the thumb, and turn it over : the mercury will run into the sealed limb. If necessary, turn it upright, pour in some more mercury, and turn flat : in this way the tube may be filled.

In the sodium sulphate experiment it is possible that when the liquid is cooled no crystals will separate. If this be the case, throw in a single small crystal of the salt : around this as a nucleus the crystals will rapidly form.

An electric battery of three or four of either Grove's or Bunsen's cells is most suitable for the decomposition of water ; the only difference between these forms of battery is that Grove employs as the positive element a sheet of platinum foil, while Bunsen uses a rod of carbon. To use the battery, first see that the zinc plates are bright all over with mercury ; if this is not the case, they should be re-amalgamated. Dip each plate in a dilute solution of sulphuric acid (1 of acid to 10 of water) ; after

half a minute remove the plate, pour a little mercury on it, and rub over every part with a piece of flannel tied on to the end of a stick until the whole surface of the zinc is bright with a coating of mercury. Place the zincs in the outer cells with the ends to which the binding screws are attached all looking the same way; put in the porous cells, and the platinum foil again inside the porous cell. Connect the end zinc of all to the conducting wire by means of a binding screw; connect together the platinum of that cell and the zinc of the next with a binding screw, letting the screw be on the zinc side and the flat part of the connection against the platinum. The platinum and zinc of each of the adjoining cells must be thus connected; the end platinum must have the second wire attached to it. At the end of the box in which the cells are supplied, there is a piece of sheet vulcanite, against which the platinum is fixed. All the connections, wires, &c., must be perfectly clean and bright. Next fill the porous cells by the aid of a funnel with the strongest commercial nitric acid, taking care that none overflows. The outer cells are to be filled with sulphuric acid of the same strength as that used to amalgamate the zincs. When the battery is finished with, unscrew the connections, wash the binding screws in a stream of water, and wipe dry with a duster. Pour the nitric acid back into a bottle kept for the purpose. The sulphuric acid may, as a rule, be thrown away; if used for only a few minutes it may, however, be employed once again. Rinse the porous cells and other parts thoroughly; before putting away, the porous cells will be all the better for soaking in clean water for a few hours. Always keep them full of water when not in use.

The most convenient apparatus for the production of an electric spark is a small induction coil. This is conveniently worked by a single bichromate cell; the advantage of this is that the cell is kept charged, the zinc being simply lifted out of the liquid. When required for use, connect by means of wires to the coil; connect also the terminals of the secondary circuit to the eudiometer; before filling it with gas, see that all is in working order; lower the zinc of the cell in the acid, tighten the binding screw, and turn on the current by means of the screw or handle fixed for that purpose on the coil; a rapid series of sparks should pass between the ends of the wires in

the eudiometer. Do not let the zinc remain in the acid longer than necessary for the experiment.

In using ether, take care to keep any light at a distance ; also replace the stopper and put the bottle in its proper place immediately. Ether is very volatile and very inflammable.

In experiment 53, the reason for filling the leading tube with water is to lessen the amount of air which is mixed with the small quantity of gas given off. An easy way to do this is to attach some india-rubber tubing to the end of the leading tube ; suck water into it from the trough or a beaker, and when full, pinch the rubber tubing, fit the cork to the tube, and allow the end to remain under the water in the trough.

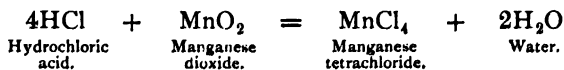
CHAPTER VIII.

CHLORINE.

Symbol, Cl. Atomic weight, 35.37. Density, 3.37. Specific gravity, 2.435. Molecular weight, Cl₂—70.74. Molecular volume, .

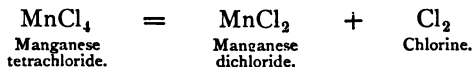
OCCURRENCE.—This gas is not known in the free state in nature, but occurs in vast quantities in combination with sodium, forming rock salt.

PREPARATION.—The gas may be readily obtained from its compound with hydrogen (hydrochloric acid, HCl), by the action of manganese dioxide ; on mixing these substances together a compound of chlorine with manganese is formed thus :—

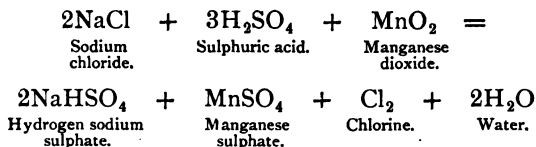


The manganese tetrachloride is an unstable compound, and, with an elevation of temperature, is decomposed into a

chloride containing half the amount of chlorine, with the separation of the remainder in the free state :—



In the actual preparation of the gas these two actions go on together, the tetrachloride being decomposed as rapidly as formed. Chlorine is manufactured in large quantities by this process for various uses in the arts. Chlorine is sometimes prepared from common salt (sodium chloride) direct, by the action on it of manganese dioxide and sulphuric acid ; the gas is disengaged in the cold, but more rapidly with the application of heat. The whole of the chlorine is liberated :—



Chlorine may also be obtained by the electrolysis of solution of hydrochloric acid.

For the study of the properties of chlorine the gas may be prepared from hydrochloric acid and manganese dioxide.

Experiment 56.—Take the apparatus No. 1, consisting of a sixteen-ounce flask, fitted with thistle funnel and leading tube. Pour into the flask sufficient strong commercial hydrochloric acid, to just cover the bottom ; then add about an ounce of powdered manganese dioxide ; next pour in three or four ounces of the hydrochloric acid, and shake the mixture well up ; fix in the retort stand, and introduce the cork. A, fig. 22 is a flask arranged for the preparation of chlorine. The gas, being soluble in rather less than half its volume of cold water, cannot well be collected over that liquid. The process of downward displacement must be employed, or the water used must be hot. Seven jars of the gas will be required for the following experiments ; it will be, as a rule, convenient to fill the jars twice. Having the

three jars and well greased plates ready, proceed to collect over hot water, if obtainable ; if not, by downward displacement. In the latter case, the colour of the gas will indicate when the jars are full. Light the Bunsen, and apply a gentle heat : the gas is readily disengaged. Having filled three bottles, remove the Bunsen, and the action will almost cease until the flame is re-applied. Under any circumstances, take care that as little gas as possible escapes in the room. Where possible, chlorine should be made in a stink-closet—*i.e.*, a closet provided with a sliding glass door and flue for the removal of obnoxious gases. If there is no other alternative but to make it in the open laboratory, have every window possible open. It must be remembered that when a flask is heated a piece of wire gauze is to be interposed between it and the flame.

PROPERTIES. *Experiment 57.*—Introduce into one jar a lighting taper : the gas does not take fire ; the taper continues burning, but with a dull smoky flame ; notice that in addition to the soot there is an abundance of white fumes produced.

Experiment 58.—Put a small piece of phosphorus in a deflagrating spoon, and, without lighting it, place in a jar of the gas : notice that it commences to burn spontaneously, but does not evolve a very bright light.

Experiment 59.—Powder very finely some metallic antimony, and drop a pinch into a bottle of the gas : it immediately takes fire.

For one of the following experiments a dry jar is required ; one must, therefore, be wiped dry with the duster and filled by displacement.

Experiment 60.—Take a small piece of sodium in a *dry* and clean deflagrating spoon ; heat in the Bunsen flame until it is quite melted ; plunge it in the *dry* jar of gas : it burns with the production of great heat, and white fumes of common salt are deposited.

Experiment 61.—Pour into one jar of gas a solution of some vegetable colouring matter, as litmus or indigo ; shake up : the colour is instantly destroyed and cannot be restored. Introduce also a moistened piece of red blotting paper : the colour is discharged.

Experiment 62.—Fit up the eight-ounce flask for the generation of hydrogen from zinc and sulphuric acid ; attach to it a

jet thus (fig. 21), with a piece of india-rubber tubing. After taking the usual precautions, light the jet and introduce it

FIG. 21.



into a jar of chlorine; notice that the gas continues to burn, and that copious fumes are formed.

The affinity of hydrogen and chlorine for each other is so great that many organic bodies containing hydrogen are decomposed by chlorine gas.

Experiment 63.—

Take a piece of tow, pull it out as loose as possible, wet with turpentine (a hydrocarbon

with the formula $C_{10}H_{16}$); drop this into a jar of chlorine: it is decomposed, usually with heat and light. The carbon is deposited as soot; the hydrogen again produces fumes of hydrochloric acid.

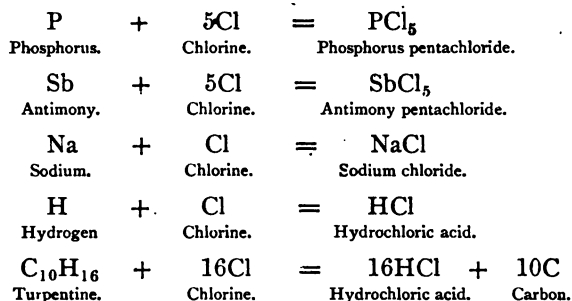
The student will now have verified many of the properties of this gas for himself in the preceding experiments. Chlorine is of a yellowish green colour, and has a most pungent and disagreeable odour, which, when much diluted with air, somewhat resembles that of seaweed. It acts as an irritant poison when in the pure state, or even when present in considerable quantity in air.

It is soluble in cold water, which, at a temperature of 15°C. , dissolves 2.368 volumes of the gas. Chlorine can be liquefied by a pressure of six atmospheres at 0°C. , but has not yet been frozen.

Like oxygen, chlorine supports combustion, and is non-inflammable; it is a most active element, forming bodies called chlorides with the whole of the elements. It has a

remarkable affinity for hydrogen : on exposing a mixture of those gases to diffused daylight, they slowly combine; bright sunlight effects their immediate union with explosion. Intense artificial light, such as that of burning magnesium, produces the same effect. Carbon does not burn in chlorine, and if bodies containing it are burned, the carbon is deposited in the free state. One important peculiarity of the combustion of bodies in chlorine is that they often spontaneously ignite. As a rule, although a lower temperature is sufficient for the commencement of the formation of chlorides, the heat evolved during the union is less than that evolved in the production of the corresponding oxides.

The chemical actions occurring in the previous experiments are represented in the following equations :—

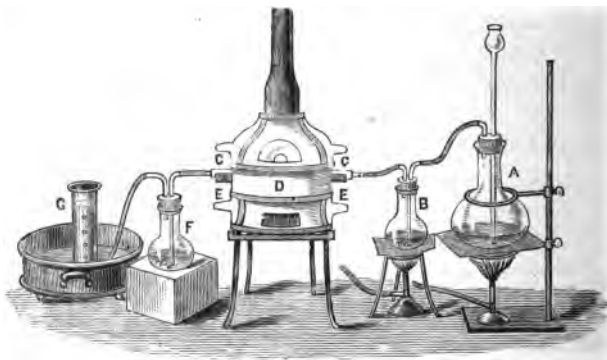


Water must be added to the list of hydrogen compounds capable of decomposition by chlorine. If a solution of chlorine in water is exposed to the sun's rays, bubbles are seen to rise to the surface which, on examination, are found to be oxygen. The experiment is best performed by inverting a gas jar filled with the solution in a small trough also containing saturated chlorine water. At a higher temperature the decomposition takes place more rapidly.

Experiment 64.—Connect a flask, A, fig. 22, fitted for the preparation of chlorine, to the second flask, B, which contains water; the leading tube from A dipping beneath the water level.

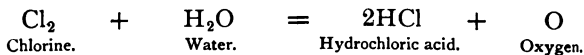
Through the charcoal furnace, D, pass a porcelain tube, C, filled with fragments of porcelain or flint, and fitted at each end with corks and glass tubes. The danger of cracking the porcelain tube is lessened by placing it in a semicircular iron trough, E, just large enough for the tube to lie in. This is conveniently made from a piece of sheet-iron, which can readily be turned up into a semicircle one inch internal diameter by any smith. F is a wash-bottle, containing a solution of caustic potash, for the purpose of removing the hydrochloric acid and any excess of chlorine; the oxygen passes over, and is collected

FIG. 22.



in the trough G. B and F are connected to the porcelain tube by india-rubber tubing. The furnace must first be lighted and the tube raised to redness; then light the Bunsens under both the chlorine and water flasks: a mixture of chlorine and steam enters the furnace, decomposition ensues, and oxygen and hydrochloric acid escape.

The reaction is thus represented :—



This experiment is an important one as showing the presence of oxygen in water; unlike hydrogen, by no known

means can the oxygen of water be displaced in two instalments.

Chlorine is one of the most powerful bleaching or decolorizing agents known ; there are few vegetable colouring matters which are unattacked by it : ink, litmus, &c., are rapidly changed into colourless bodies. Mineral ink, or printer's-ink, is not changed. Chlorine has no bleaching action in the absence of water ; in its presence, that compound is decomposed with the formation of hydrochloric acid. The oxygen *at the moment of liberation*, combines with the colouring matter and produces a compound containing a higher proportion of oxygen, and devoid of colour. At the moment of liberation from a compound an element is said to be *nascent* ; why at this time it should be so much more active than ordinary, will be better understood when the student's knowledge of chemical theory is more extended. Free oxygen has little, if any, bleaching power.

Summary.

Chlorine is a heavy gas ; does not occur in nature in the free state, but largely in combination with sodium. May be obtained from either hydrochloric acid or sodium chloride, or by electrolysis of hydrochloric acid. Possesses a yellow-green colour ; odour somewhat like sea-weed, and acrid taste ; non-inflammable ; supports combustion ; soluble in water ; is a powerful bleaching agent ; decomposes water with evolution of free oxygen.

Laboratory Hints.

Chlorine rapidly attacks corks ; they may be protected by dipping them into melted paraffin ; not *paraffin oil*, but the solid substance melted in a small dish or pipkin. The reason for *first* adding hydrochloric acid, subsequently the manganese dioxide, and shaking up so thoroughly, is that otherwise the oxide is liable to form a cake at the bottom ; this gets hot, and the liquid, finding its way through it after a time, cracks the vessel.

The fumes produced by burning both phosphorus and antimony in chlorine are poisonous, and should not be breathed.

The reason why such care must be taken to have dry jars for sodium experiments is that hot sodium accidentally coming in contact with water explodes violently. See also that there is no water spilled about the working bench. For the hydrogen experiment a second generating apparatus is required ; a second thistle funnel is a useful addition to the apparatus list given on page 9. Failing this, all other experiments with chlorine may be first tried, and then the apparatus cleaned and used for hydrogen. In the last experiment there is considerable danger of breaking the porcelain tube ; it is a good plan to incline it a little, so that the steam in passing through it has to rise ; this prevents any condensed steam running on to the red-hot porcelain. When the experiment is finished, disconnect the other apparatus, and allow the tube to cool slowly in the furnace.

Wash all apparatus used for chlorine immediately it is finished with ; this applies especially to corks and india-rubber tubing : the latter should have a stream of water sent through it.

CHAPTER IX.

HYDROCHLORIC ACID.

Formula, HCl. Molecular weight, 36.5. Density, 1.25. Specific gravity, 1.2474.

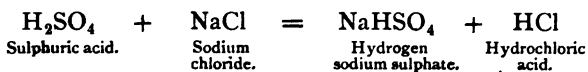
This gas, called also muriatic acid, is the only known compound of hydrogen and chlorine. Its formation, by the union of these elements, has been already described.

PREPARATION.—The gas is easily obtained by the action of sulphuric acid on almost any chloride ; because of its cheapness, common salt is usually employed. Salt in its ordinary form is so finely divided that the action proceeds with almost unmanageable rapidity. This may be modified by first fusing the salt and then breaking the solid mass thus obtained into small lumps. The gas is extremely soluble in

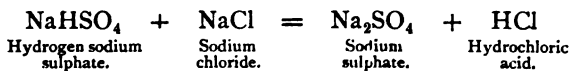
Preparation and Properties of Hydrochloric Acid. 79

water, and therefore has to be collected by downward displacement.

The reaction is represented by the following equation :—



One atom of the hydrogen of the sulphuric acid is here driven out by the sodium. At a much higher temperature than could be used with a glass flask, the second atom of hydrogen is displaced :—



Experiment 65.—Fill a clay crucible about five inches in height with common salt ; melt over a bright red fire or in a furnace, and pour the molten mass on to a cold iron plate. When cold break up and store in a bottle, which must be kept corked. Place about half an ounce of the fused salt in the generating flask with funnel and leading tube arranged for downward displacement ; see that the india-rubber and other tubes are dry. Fix in the retort stand and pour in sufficient concentrated sulphuric acid to cover the salt : the gas is evolved rapidly even in the cold. Thoroughly dry three gas jars and fill them ; should the evolution of gas slacken, apply heat. Copious fumes emerge from the mouths of the jars as soon as full. Next place the delivery tube in a beaker with a small quantity of water : notice that the gas is absorbed as rapidly as formed.

PROPERTIES. *Experiment 66.*—Take the plate off one jar of gas ; observe that although the gas itself is clear, the fumes seen so frequently before again make their appearance when the gas comes in contact with the air. Introduce a lighted taper : the taper is extinguished, and the gas itself does not light.

Experiment 67.—Place the mouth of the second jar under water and slide off the glass plate ; the water rapidly fills the jar.

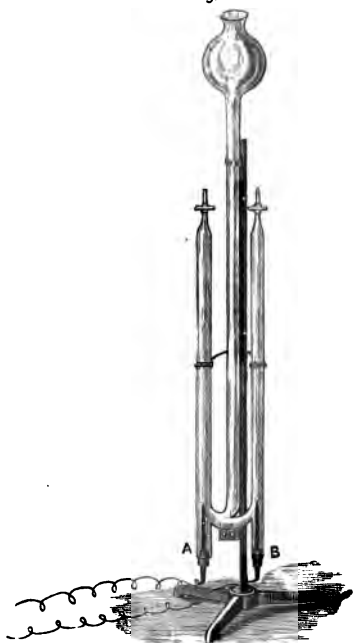
Experiment 68.—To the third jar add some litmus solution

and shake up; the colour is seen immediately to change to red.

Examine now the solution made by passing the gas into water; it possesses the odour of the gas, and, like it, immediately reddens litmus.

Hydrochloric acid is colourless, but is rendered visible, on

FIG. 23.



coming in contact with air containing moisture, by the formation of a compound with water which condenses to liquid globules; hence the dense fumes so often noticed. It has a sharp pungent odour, its solution in water is intensely sour, and reddens litmus solution; it is a very powerful acid, and forms an important series of salts known as chlorides. Water at 15° C. dissolves 454 volumes of hydrochloric acid. The composition of the gas may be ascertained by exposing its solution to electrolysis, when it is resolved into equal volumes of hydrogen and chlorine.

The best apparatus to use for this experiment is Hofmann's, which, as shown in Fig. 23, consists of three tubes, connected at the bottom; through A and B are passed india-rubber corks with carbon electrodes (platinum cannot be used, as that metal is attacked by nascent chlorine).

Experiment 69.—Fill the apparatus with concentrated hydrochloric acid just to the level of the stop-cocks, leaving

them open ; connect with a battery of three or four cells, and allow the current to pass for an hour ; the hydrogen rises rapidly from the negative electrode, but from chlorine being soluble in water, little gas is evolved until the solution is saturated. At the end of this time, turn off the stop-cocks : equal volumes of gas should collect in each tube. Should the chlorine be in too small a quantity, it is a sign that the acid in that limb is not yet saturated. The chlorine may be recognised by its colour ; open the stop-cock, and let the gas impinge on a piece of wet litmus paper : the colour of the litmus is discharged. Connect a small glass jet to the limb containing hydrogen by india-rubber tubing ; open the stop-cock and apply a light to the issuing gas, which is recognised by its inflammability.

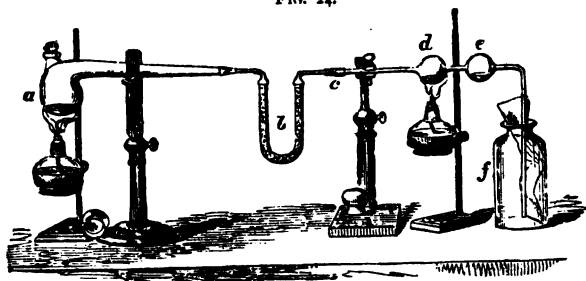
Chlorine, like oxygen, is liberated from the electrode connected with the copper or platinum element of the battery. The following eight elements are alike in this respect, and from their behaviour with an electric current, are called negative:—oxygen, chlorine, bromine, iodine, fluorine, sulphur, selenium, and tellurium.

In the event of the apparatus for performing the last experiment not being obtainable, the presence of both chlorine and hydrogen in hydrochloric acid may be detected in the following manner.

Experiment 70.—Fit to the generating flask, containing salt and sulphuric acid, the apparatus used for dry hydrogen in experiment 39 ; connect this to a tube in which two bulbs have been blown : in the first of these place some powdered manganese dioxide, which has been thoroughly dried by warming in an iron ladle over the Bunsen flame. Arrange a bottle to receive the escaping gas ; place in it a sheet of moist blue litmus paper. The hydrochloric acid evolved at once changes the colour. Apply heat to the bulb containing manganese dioxide : the hydrochloric acid is decomposed ; water collects in the second bulb ; chlorine passes over into the jar, and is recognised by its odour and bleaching power. Fig. 24 shows the apparatus which may be used for this experiment, a retort being employed instead of the generating flask : *a* is the retort ; *b* the drying tube connected to the bulb-tube at *c* ; *d* is

the bulb containing manganese dioxide; water collects in *e*; and chlorine passes over into *f*.

FIG. 24.

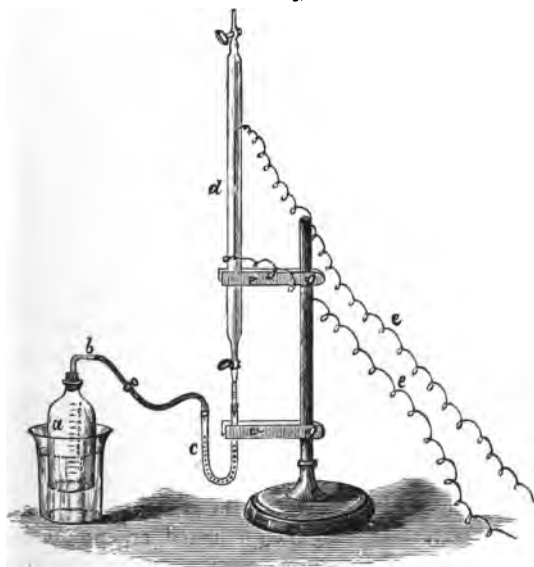


The composition of hydrochloric acid by synthesis is shown by the explosion of hydrogen and chlorine in equal volumes in a specially constructed tube. The gases for the purpose are conveniently prepared by electrolysis; or working by gas or diffused daylight, they may be mixed in a bottle over saturated chlorine water in a small trough or beaker, and then transferred to the explosion tube: this simply consists of a glass tube about twenty inches in length, with a stop-cock at each end, and two platinum electrodes fused through the middle.

Experiment 71.—Procure a small gas jar *a*, Fig. 25, open at top and bottom; one holding 20 or 32 ounces is a convenient size. Close the upper opening with a cork which has been dipped in melted paraffin. Bore a hole and pass through it a glass tube with stop-cock. Failing this, a plain glass tube with a piece of india-rubber tubing and a pinch-cock may be used. Turn the jar *a* bottom upwards and exactly upright, and proceed to graduate it by pouring in successive quantities of 25 or 50 cubic centimetres of water, making a mark at the level of each on the outside of the jar either with a sharp file or a writing diamond. These marks should be numbered, 1, 2, 3, &c., from the top of the jar downward. Having prepared the jar, stand it in a small trough or large glass beaker, filled with saturated chlorine water; pass the india rubber tubing over *b*, allow the air to

escape from the jars, and close the screw tap; next introduce through *b* 200 cubic centimetres of hydrogen, and then the same quantity of chlorine, and agitate the jar, so as to mix the gases. Connect the glass tube *b* with the small U-tube *c*, filled with calcium chloride, and attach the explosion tube *d* to the second end of the U-tube. Open the whole of the stop-cocks sufficiently for the weight of the jar *a* to force the mixed gases *slowly* up into and through *d*. When nearly the whole

FIG. 25.



of the gas has been allowed to escape, close the stop-cocks: *d* is now filled with a mixture of equal volumes of dry hydrogen and chlorine, which has expelled the air. Attach the wires *e e* from the induction coil to the electrodes, and pass an electric spark: combination takes place between the gases. When they have cooled down to the original temperature, place one end of the explosion tube under the surface of mercury and open the stop-cock: the mercury does not rise, showing that there is no alteration in the volume of the gas. Remove and open the

stop-cock with the end immersed in water : the water rushes up and fills the whole of the tube.

These experiments show that hydrochloric acid is a gas produced by the union of equal volumes of hydrogen and chlorine without condensation. The composition by weight may be demonstrated by means similar in principle to those adopted in the case of water.

Summary.

Hydrochloric acid is the only compound known of hydrogen and chlorine ; may be easily prepared by the action of sulphuric acid on a chloride. The gas is very soluble in water ; is colourless, but fumes on exposure to air ; has a sharp pungent odour and sour taste ; is non-inflammable, and a non-supporter of combustion ; reddens litmus. Is composed of equal volumes of hydrogen and chlorine united without condensation : this is proved both by analysis and synthesis.

Laboratory Hints.

Fused salt is as a rule kept in a laboratory ; it is a convenient plan to get a working jeweller to melt down a good stock in one of the large crucibles used in the trade : the cost for melting would not be excessive.

It is not absolutely necessary in experiment 70 that the tube containing manganese dioxide should have bulbs blown on it : bending it in the form of a W answers the purpose.

The graduated jar and explosion tube for experiment 71 will, in most cases, be found among the general apparatus of the laboratory. Instead of using the graduated jar, and thus mixing the gases, they may be prepared electrolytically with the same apparatus used for obtaining the mixed gases from water ; the bottle should, however, be a small one, and the electrodes must be of carbon. The electric current must be passed for a sufficient time to saturate the acid with chlorine. Instead of graduating the jar in cubic centimetres, fluid ounces may be used as the unit ; then 4 ounces in volume of each gas should be employed.

As it is possible that the explosion which takes place when the spark is passed through the tube containing the mixture of

gases might shatter the tube, the precaution of placing it in a sink closet and shutting the door is advisable. The eudiometer in which oxygen and hydrogen were exploded over mercury cannot be employed, because mercury is rapidly attacked by chlorine. It is essential that the tube should be *dry* before being filled with the gases; to ensure this it should first be warmed in the hot-water oven and the water vapour sucked out.

CHAPTER X.

LAWS OF CHEMICAL COMBINATION BY WEIGHT AND VOLUME.

THE student is now in a position to appreciate the reasoning on which the atomic theory is based. The experimental work of the last few chapters will have furnished him with some specimens of the observations which are explained by this theory; he will do well, with this more intimate knowledge of experimental data, to go back to Chapter IV., and once more carefully read it through. It is there stated that each element has a certain number given it, which represents the weight of that element which enters into a chemical compound, and that, of all the elements, hydrogen is represented by the smallest number. Proof of this law of definite proportion by weight is afforded in the experimental determination of the composition by weight of water. Proper precautions being taken, it is invariably found that in 9 parts of water, there are 1 of hydrogen and 8 of oxygen by weight. Judging from this fact alone, we might ascribe to oxygen 8 as its combining proportion.¹ This would give as the formula of water HO ; but from the experiments in which hydrogen is displaced from water in two distinct instalments, it is evident that there must be two combining proportions of that

¹ In these explanations, for the sake of simplicity, the nearest whole numbers are taken for the atomic weights.

element present. Therefore, for this and other reasons, water is considered to consist of two combining proportions of hydrogen to one of oxygen; consequently, 2 parts of hydrogen by weight are looked on as combining with 16 by weight of oxygen; and, as no less proportion of that element is ever displaced from a chemical compound, 16 is taken as the combining weight of oxygen.

In addition to water another compound of hydrogen and oxygen has been described, in which 2 by weight of hydrogen are in union with 32 of oxygen. This compound has accordingly received the formula H_2O_2 . Not only then does chemical combination invariably occur in *definite proportions*, but also, when two elements happen to combine in more than one proportion, they unite in *multiple proportions*. In the second compound of hydrogen and oxygen there is exactly *twice* as much oxygen as in the first. Although the number of chemical compounds is so vast, no deviation from this law has been observed.

The weight of an element which combines with, or by displacement expels from a compound, 1 part by weight of hydrogen, is termed its *chemical equivalent*. The number is in many cases the same as the atomic weight; it must, however, be remembered that 'chemical equivalent' and 'atomic weight' are terms which have distinct and separate meanings.

It is to John Dalton of Manchester that we owe the first explanation of the reasons why combinations are always found to obey this law. He was led to answer the question by assuming that matter is built up of extremely small particles, which are indivisible, and that, when substances are caused to combine, it is between these particles that chemical union occurs. The name atom is derived from the Greek α , not, and $\tauμνω$, I cut, and essentially signifies that which is indivisible. Atoms of the same elements are supposed to be of the same size and weight. The reason, therefore, according to the atomic theory, why combination

occurs in multiple proportions is that when two elements combine, one atom of the first may combine with one, two, or three atoms of the second, but combination with the *fraction* of an atom is necessarily a contradiction. Though the theory is not one which admits of absolute proof, yet it so amply and consistently explains all the phenomena of chemistry, that its essential principles are universally recognised.

In assigning an atomic weight to an element, chemists are guided by several considerations ; the extended study of these must be postponed until the student's knowledge is more advanced.

The formula of a compound gives the number of atoms of each constituent ; those atoms each being of a definite weight, we are enabled to state the proportion by weight of each element in a compound. Thus the formula of potassium chlorate is KClO_3 , assigning to each of these their atomic weight, we have :—

$$\begin{array}{rcccl} \text{K} & \text{Cl} & \text{O}_3 & & \\ 39 & + & 35.5 & + & (16 \times 3 = 48) = 122.5 \end{array}$$

that is, the molecule weighs 122.5, this being the sum of the weight of the constituent atoms. As any weight taken of this salt must consist of a whole, though indefinite, number of molecules, the proportion by weight of each element present is the same as that in the individual molecule.

This fact will be grasped more clearly when it is remembered that these very combining weights are numbers deduced from experiments made on the substances taken in quantity.

From the molecular weight of a compound its percentage composition, or weight of each constituent in 100 parts, is easily found by a calculation in proportion. Thus, in the case of potassium chlorate, 122.5 contain 48 of oxygen; what quantity will 100 contain?

$$\begin{array}{rcl}
 \text{As } 122.5 : 100 :: 48 & : & 39.18 \text{ per cent. of oxygen.} \\
 \text{,, } 122.5 : 100 :: 35.5 & : & 28.97 \quad \text{,,} \quad \text{,,} \quad \text{chlorine} \\
 \text{,, } 122.5 : 100 :: 39 & : & 31.83 \quad \text{,,} \quad \text{,,} \quad \text{potassium.} \\
 & & \underline{99.98}
 \end{array}$$

Precisely the same method applies to any and every other compound.

An important, but somewhat more difficult, type of calculation is that in which the percentage composition of a compound is obtained by analysis, and its formula is required. The results of analysis are almost always expressed as so much per cent. ; suppose that the figures given above represent results obtained in the case of potassium chlorate, and that the formula is required.

Knowing that the actual weight of oxygen present is 39.18, it is necessary first to ascertain what number of atoms this represents, and so with the other elements.

$$\begin{array}{rcl}
 \frac{39.18}{16} & = & 2.448. \\
 28.97 & = & .816 \\
 35.5 & & \\
 \frac{31.83}{39} & = & .816
 \end{array}$$

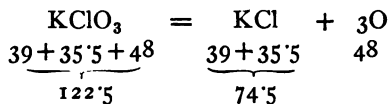
In this way we find that 39.18 by weight of oxygen in 100 parts represents 2.448 atoms of oxygen ; and that of chlorine and potassium there are .816 of an atom of each. But atoms are indivisible, and therefore these numbers only represent the ratio or proportion of the number of atoms to each other. The next step in the calculation is to find the smallest series of whole numbers which have the same ratio: dividing each of the numbers above by the lowest we have :—

$$\frac{2.448}{.816} = 3 \text{ of O.} \quad \frac{.816}{.816} = 1 \text{ of Cl.} \quad \frac{.816}{.816} = 1 \text{ of K.}$$

The formula is therefore considered to be KClO_3 . In assigning a formula to a compound, however, other considerations must not be overlooked ; because the percentage composition will be the same whether we look on KClO_3 or $\text{K}_2\text{Cl}_2\text{O}_6$ as the formula. The above reasoning is conveniently summed up in the following rule for determining the percentage composition.

Rule.—Divide the percentage of each element by its atomic weight ; divide each of the numbers thus obtained by the lowest one of the series ; the quotients are generally whole numbers, or practically so. These represent the number of atoms of each element present in the molecule. In some cases the result of such division is that one quotient contains $\cdot 5$, i.e. one atom of one element to a proportion of $1\cdot 5$ or $2\cdot 5$, &c., of another ; the number of atoms in the molecule is then obtained by doubling every number, making 2 of one to 3 or 5 of the other.

The student is not expected at this stage to determine whether the formula is really KClO_3 or $\text{K}_2\text{Cl}_2\text{O}_6$. By the above method the simplest formula of any compound is obtained ; other considerations, of which a knowledge of the vapour density is the most important, must determine whether the formula is or not a multiple of this. As a matter of fact potassium chlorate, which has been taken as a convenient instance, is represented by KClO_3 ; its vapour density cannot, however, be taken, as at a comparatively low temperature it is decomposed. The formula representing the weight of each element present in a compound, it is but a step further in the same line of reasoning to say that an equation must represent the weight of each substance involved, and of each body produced, in a chemical change.



122·5 of potassium chlorate yield on decomposition 74·5

of potassium chloride and 48 of oxygen. It is most important that the student should remember that in every case the equations and atomic weights supply the data by which weights of bodies produced from certain weights of the substances which yield them may be calculated. On the other hand, given the quantity of a compound required, the weight of each body necessary for its production may be determined. Let this fact be once grasped, no difficulty should be found in making any of these calculations, the principles being always the same. It is scarcely necessary to remark that unless the student knows the equation representing the chemical change, and the atomic weights, he will be at fault.

The one example given below should make the whole subject clear to those who understand the *principles* involved.

From 3 grams of potassium chlorate what weight of oxygen may be obtained, and what weight of potassium chloride will remain?

The equation shows that 122.5 of potassium chlorate yield 74.5 of potassium chloride, then :—

As 122.5 : 74.5 :: 3 : 1.824 grams of KCl remaining.

As 3 : 1.824 :: 100 : 60.8 = percentage of KCl.

3 - 1.824 = 1.176 grams of oxygen yielded.

As 3 : 1.176 :: 100 : 39.2 = percentage of oxygen.

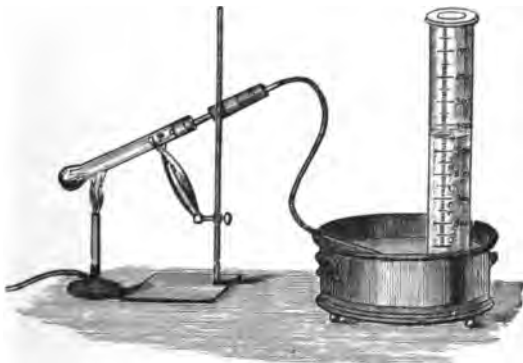
The fact that the quantities calculated from this equation actually represent those obtained is proved by the following experiment.

Experiment 72.—Take a test-tube made of combustion tubing six inches long and half an inch internal diameter; fit to it a cork and leading tube about two inches long. Cut a piece about two inches in length from a glass tube about half an inch diameter; fit a cork to each end; insert the leading tube from the test-tube into one cork; push in through the other end a loosely fitting plug of cotton-wool, and through the

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cork pass a small piece of glass tubing. See that the joints are perfectly air-tight, by sucking at the end leading tube and closing the tube with the tongue ; the comparative vacuum thus produced should not sensibly diminish during a few seconds. Dry the whole apparatus thoroughly, by wiping with a dry and clean duster; next weigh it. Before beginning to fit these parts together, a small quantity of potassium chlorate should be powdered and placed in the hot-water oven to dry. Having noted the weight of the apparatus, take the test-tube and scoop into it three grams or thereabout of the dry potassium chlorate ; give the tube a tap, so as to get all the salt at the bottom ; wipe out any particles adhering to the side of the tube with a small

FIG. 26.



brush, or the corner of the duster ; again weigh and note the weight. Connect the leading tube by india-rubber tubing to a glass tube placed in the pneumatic trough. Fix the test-tube in the retort stand, so that it is at an angle of 45° . Procure a tall graduated litre jar (a test-mixer) ; fill with water, and invert in the pneumatic trough to receive the gas. Fig. 26 shows the whole apparatus arranged for the evolution of oxygen. Warm the tube very gradually with the Bunsen : the salt melts and readily gives off oxygen. After a time, however, it becomes somewhat pasty, and the gas comes off less readily. At this point, place the flame a little above the salt, and heat carefully, working down toward the bottom. Toward the end, heat the

tube as strongly as possible with the Bunsen ; turn it round, so that the whole of the salt is acted on ; when no more gas is evolved, disconnect the india-rubber, and allow the apparatus to cool. The principal chances of failure are that the heat may so soften the glass that the gas may blow a hole through, and that at the moment when the pastyness is produced, the salt may bubble up into the higher part of the tube, and into the leading tube. This may be prevented by careful watching, using a tube of not less diameter than that given, and getting the tube hot just above the salt ; any which bubbles up is thus liquefied at the high temperature, and again runs back to the bottom. The little tube containing cotton-wool is fixed to retain any potassium chloride carried over mechanically with the gas. Remember that the plug must not be too tight, and that it must be at the end furthest from the generating tube.

When cold, weigh the tube and potassium chloride, and find what weight remains. Observe the volume of oxygen in the measuring jar, when it is depressed until the level of the water inside corresponds with that in the trough. With a thermometer take the temperature of the water, and calculate what volume the oxygen would be at 0° C. Then find by calculation its weight. One litre of oxygen at N.T.P. weighs 1.4336 grams.

The following are results obtained in this experiment by a student working in the author's laboratory :—

Weight of apparatus and KClO_3	.	43.68	grams
Weight of apparatus . . .	.	40.68	„
Weight of KClO_3 . . .	.	<u>3.00</u>	„
Weight of apparatus and KCl .	=	42.62	„
Weight of apparatus . . .	.	40.68	„
Weight of KCl} . . .	.	<u>1.94</u>	„

As 3.00 : 1.94 :: 100 : 63.7 per cent. of KCl .

Volume of oxygen collected at 20° C. = 900 c.c. Reduced to standard temperature, correction for pressure being neglected,

$$\frac{900 \times 273}{293} = 838 \text{ c.c. at } 0^{\circ} \text{ C.}$$

1000 c.c. of oxygen weigh 1.4336 grams.

As 1000 : 838 :: 1.4336 : 1.2013 grams of oxygen.

As 3.00 : 1.20 :: 100 : 40.0 per cent. of oxygen.

	Found	Theoretical
Potassium chloride	1.94 = 63.7 per cent.	1.824 = 60.8 per cent.
Oxygen	1.20 = 40.0 „ „	1.176 = 39.2 „ „

The potassium chloride is probably over estimated, through some of the chlorate remaining unreduced to chloride. The oxygen is so through the air in the test-tube expanding and being thus driven over. With care, however, results may be obtained which prove the general truth of the fact that the equation represents the weights of the various participating bodies; the error of experiment, even with a young student, should come within 4 or at most 5 per cent.

The term atom is applied to the smallest particle of an element entering into or leaving a chemical compound; thus, when hydrochloric acid is decomposed, we say that an atom of each element is liberated. The atoms of elements, when in the free state, are not, however, supposed to remain single, but in most cases unite together to form molecules of the element; thus, two atoms of hydrogen unite to form a molecule of hydrogen: this union is attended with loss of the chemical activity of the element. It has been explained that *nascent* oxygen, liberated by chlorine, is a powerful bleaching agent, while free oxygen is not so. The theory on which this is accounted for is as follows: at the moment of liberation the oxygen exists as *atoms*, and these attack the colouring matter; failing anything else with which to unite, they unite with each other and form molecules. The activity of the oxygen molecule is less than the sum of that of the two

atoms by the amount of energy with which they are held together. In one striking experiment which the student has performed, the affinity of oxygen atoms for each other is greater than that for the bodies with which they are combined ; the experiment referred to is that in which hydroxyl and silver oxide are brought together. The affinity between the oxygen and silver is but small ; so also is that between the water and second atom of oxygen which has changed it into hydroxyl. The attraction of the oxygen atoms for each other is sufficient to overcome these ; and accordingly that element is liberated in the free state. Considerations of this kind have led the chemist to the conclusion that the atoms of elements combine together to form molecules.

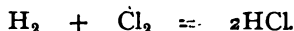
The fact that all gases expand at the same rate when heated, leads us to the conclusion that their molecular constitution is alike. This is the basis of what is known as Avogadro's law, viz. '*Under similar conditions of temperature and pressure, the same volume of any gas contains the same number of molecules.*' This is equivalent to saying that the molecules of all gases are of the same size. The relative weights of equal volumes of hydrogen and hydrochloric acid are 1 and 18.18. These, according to Avogadro, are the relative weights also of the molecules. By experiment we know that hydrochloric acid contains half its volume of hydrogen ; it must therefore contain half as much of that element as an equal volume of free hydrogen. The molecule of hydrogen then contains double as much hydrogen as is contained by a molecule of hydrochloric acid which is of the same size. As we assume that the hydrochloric acid molecule contains at least one atom of hydrogen, the molecule of hydrogen must necessarily be composed of at least two atoms. The fact that two atoms of hydrogen are present in water was proved by its being removed in two successive portions ; as the hydrogen of hydrochloric acid cannot be thus removed, this is strong evidence in favour of its containing *only* one atom ; and as the quantity of hydrogen in the hydrogen

molecule is double that in hydrochloric acid, it must be composed of two atoms and no more than two.¹ As the molecule of hydrogen consists of two atoms, its weight must be taken as 2, and that of the molecule of hydrochloric acid as 36·37.

Instead of representing the combination of hydrogen and chlorine by



it is preferable to write

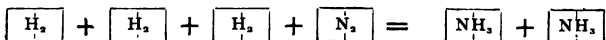
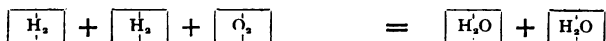


H_2 signifies that the molecule contains two atoms. As a rule, these 'molecular' equations will, in the succeeding chapters, be employed.

The molecules of the following elements contain two atoms : hydrogen, chlorine, bromine, iodine, oxygen, sulphur, selenium, tellurium, and nitrogen.

Ozone contains three atoms of oxygen in the molecule.

The student has seen that two volumes of hydrogen combine with one of oxygen to form two volumes of water gas. This is a necessary result of Avogadro's law ; because the molecule of steam is only of the same size as a molecule of hydrogen : a still further condensation occurs in the production of more complex molecules. In the following equations the molecule is represented by two squares, indicating that the volume is double that of an atom :



The first two reactions are already familiar to the stu-

¹ For further information on this point the student should consult Tilden's *Introduction to Chemical Philosophy*, from which the substance of this paragraph is taken.

dent, the last represents the composition of ammonia gas ; three volumes of hydrogen and one of nitrogen produce only two volumes of gaseous ammonia (NH_3). The gaseous volume of elements in a compound is not only definite, but the volume of each element present is represented by a whole number.

As the molecules of all elementary gases are of the same size, and the majority contain two atoms, their density, compared with hydrogen taken as unity, must be represented by their atomic weight, because the molecule of hydrogen weighs $1 \times 2 = 2$, that of oxygen $16 \times 2 = 32$, and so on. The density of any compound gas is obtained by halving its molecular weight : for example, the molecule of steam weighs 18, and occupies the same space as the molecule of hydrogen, which weighs 2 ; the quantity of steam occupying the same space as 1 volume of hydrogen must weigh $\frac{18}{2} = 9$.

Hydrogen being taken as the unit of density, its absolute weight is of great importance. As a result of most careful weighing, it has been found that 1 litre of hydrogen at the normal temperature and pressure weighs 0.0896 gram, or 11.2 litres weigh 1 gram. This figure 0.0896 gram is one which it is absolutely necessary that the student should remember : that the exact weight of 1 litre of hydrogen at 0°C . and 760 m.m. pressure is 0.0896 gram, must therefore be thoroughly imprinted on the student's mind. Knowing this, there is no difficulty in calculating the weight of any other gas whose composition is known. The density of oxygen being 16, the weight of 1 litre $= 0.0896 \times 16 = 1.4336$ grams. The weight of a compound gas is found with equal readiness. The density of hydrochloric acid is 18.18 ; therefore, the weight of a litre $= 0.0896 \times 18.18 = 1.6289$ grams.

This amount 0.0896 is of such frequent occurrence in chemical calculations that it has been proposed to give it a distinct name 'Crith : ' the weight of a litre of any other gas is then expressed as so many criths.

Summary.

That elements combine in definite proportions is proved by experiments on the composition of water. When more than one compound of two elements is known, the proportions present are multiples of the atomic weight. Dalton explained this by assuming that combination occurs between atoms. The weight of each element in a compound can be deduced from the formula and atomic weights of the elements present; the percentage composition may be calculated from these. From the percentage composition of a compound its formula may be obtained by calculation. An equation gives the weight of each element and compound participating in a chemical reaction. From these may be reckoned the weight of any one body necessary for the production of a certain quantity of another; as, for instance, the quantity of potassium chlorate necessary to produce a certain weight of oxygen, or the weight of oxygen that may be obtained from a certain weight of potassium chlorate. That the equation gives these weights may be determined by experiment. Atoms of elements in the free state unite to form molecules. The molecules possess less energy than the atoms; therefore, a gas when nascent is more active. The affinity between atoms of the same element is in some cases sufficiently great to cause the decomposition of unstable compounds. Molecules are all of the same size; the molecule of hydrogen contains two atoms. Even molecules containing a large number of atoms are of the same size as a molecule of hydrogen; hence the union of hydrogen and oxygen to form water is accompanied by condensation. The density of most elementary gases is identical with their atomic weights, and of all gases, both elementary and compound, is half the molecular weight. The weight of 1 litre of hydrogen at N.T.P. = 0.0896 gram; this number \times density = the weight of 1 litre of any other gas.

CHAPTER XI.

NOMENCLATURE, ACIDS AND ALKALIES, ETC.

THE names given to the elements are as a rule in no way connected with their properties : the only attempt at system is that the termination *um* is restricted to the metals. Selenium and tellurium, however, are exceptions, as, when discovered, they were supposed to be metallic elements. It has been proposed to change the names to selenion and tellurion ; this has not, however, met with general acceptance.

Bodies which contain only two elements are called *binary compounds*. Their names are fixed by rule ; but in the case of the more well known compounds, the old or 'trivial' names are almost always used ; no one would think, for example, of calling water hydrogen monoxide. The name of a body should, as far as possible, indicate its composition ; this end is attained by making the name of a binary compound consist of derivatives of the names of the two elements. There are unfortunately several modifications of each name, different chemists using different methods of nomenclature ; the student must make himself familiar with the whole, as, in the course of reading, he is sure to meet with the same body under names different from one another. Very little practice is, however, sufficient to overcome this difficulty.

The most frequently occurring binary compounds are those composed of a metal and non-metal ; the name of the metal is first written, and one or more syllables being removed the termination *ide* is added to the name of the non-metal. The compound of copper and oxygen is thus called *copper oxide*, that of copper and sulphur, *copper sulphide*, and so on for other compounds. These names are sometimes written *oxide of copper* and *sulphide of copper* respectively. Another plan consists of changing the Latin

name of the metal into an adjective by substituting *ic* for its last syllable ; the above names thus become *cupric oxide* and *sulphide*.

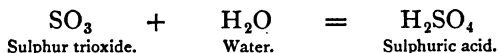
We frequently find that more than one compound of the same elements is known ; it then becomes necessary to use names which shall discriminate the one from the other. Oxygen and copper combine in two different proportions, represented by the formulae CuO and Cu_2O ; the name oxide is common to both, but the second is called *cuprous oxide*. The termination *ous* is applied to the compound containing the lower proportion of oxygen or other non-metallic element. Where there are two or more atoms of the metalloid present in a compound, the distinction is marked by the use of a prefix to the second name indicating the number. The two oxides of barium, BaO and BaO_2 , are thus known respectively as barium monoxide and dioxide. Occasionally the prefixes *proto* and *per* are attached to the second name ; *proto* to the compound in which the lower proportion of the non-metallic element occurs, *per* to that containing the higher : barium monoxide and dioxide become barium protoxide and peroxide. There is one series of oxides in which there are two atoms of the metal to three of oxygen as Fe_2O_3 ; these are sometimes termed sesquioxides : the name is, however, dying out. Where there are several binary compounds of the same elements, or where the molecule is a complex one, the number of atoms of each element is indicated by a prefix thus, Triferric tetroxide, Fe_3O_4 . In binary compounds among the non-metals, the termination *ide* is usually given in preference to oxygen, chlorine, and sulphur ; thus we have carbon oxides and sulphides, phosphorus chlorides, and chlorine oxides.

The most important compounds containing more than two elements are those produced by the union of water with oxides, forming acids and hydrates.

In experimenting with oxygen, the student will have

observed that certain oxides dissolved in water turn litmus solution red, while others restore to the reddened solution its blue colour. This reaction serves to divide the various oxides into two important classes. Those in the first series are found to have a sour taste, and consequently receive the name of acid, from their being produced by combination of various elements with oxygen, which thus received its name, it being derived from words signifying *acid-former*. There are acids known which do not contain oxygen; the number, however, is not very great. An *essential* constituent of all acids is hydrogen; and although one or two oxides are still called acids, as CO_2 , which is sometimes described as carbonic acid gas, this is apparently becoming obsolete.

AN ACID is defined as a body containing hydrogen which may be replaced by a metal (or group of elements) when presented to it in the form of an oxide or hydrate. Acids as a class are sour, and very active bodies. They are divided into hydracids in which oxygen is absent, as hydrochloric acid HCl , and oxy-acids which contain oxygen, as sulphuric acid H_2SO_4 . The oxy-acids are derived from oxides by the addition of water; thus, sulphuric acid is formed by the addition of water to sulphur trioxide :—



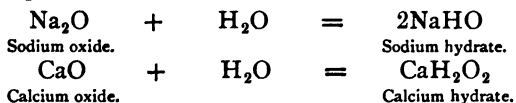
The oxides, which in this way produce acids, are called anhydrous acids or anhydrides. Anhydrides are either oxides of non-metals, or higher oxides of some of the heavy metals.

The class of oxides which, when dissolved in water, restore the blue colour to reddened litmus, are called alkalies; they form a subdivision of a larger class of oxides, the whole of which combine readily with acids, and are known as bases.

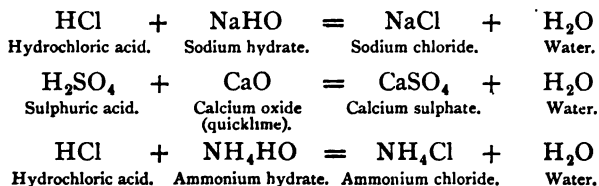
A BASE is a compound, usually an oxide or hydrate, containing a metal (or group of elements) capable of replacing the hydrogen of an acid. Bases are mostly metallic oxides.

AN ALKALI is a base of a specially active character, soluble in water, to which it imparts a soapy taste and touch. Alkalies restore the blue colour to reddened litmus. The principal alkalies are sodium hydrate, NaHO, and potassium hydrate, KHO. A solution of ammonia gas in water is also alkaline, NH₄HO.

The hydrates are mostly compounds of metallic oxides with water ; they are sometimes termed hydroxides, or hydrated oxides. Their formation is represented by the following equations :—



A SALT is the resultant body from the action of an acid and base on each other ; the metal of the base replaces the hydrogen of the acid, and water is formed. The action of the stronger acids and bases on each other is very violent ; the resultant salts are usually without action on litmus. This is, however, not always the case ; for when a strong acid combines with a weak base, the salt is acid to litmus : nitrate of mercury is an example. When the base is a strong one and the acid weak, as in sodium carbonate, the salt has an alkaline reaction. Litmus is itself a salt of a vegetable acid and base possessing a blue colour. An acid, when added, displaces the weak vegetable one, and forms a salt with the base ; the litmus acid, being red, gives the solution a red tint. On adding a base, it combines with the acid ; the litmus acid and base being liberated, again unite with the restoration of the blue colour. The following are instances of the formation of salts by the union of acids and bases :—

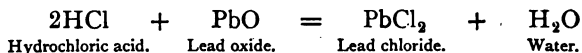


The acids are sometimes termed salts of hydrogen ; thus, sulphuric acid would be called hydrogen sulphate.

Paper tinted yellow with turmeric is also used as a test for alkalies, which give the paper a reddish brown hue.

Experiment 73.—Take a dilute solution of hydrochloric acid ; dip into it some paper coloured blue with litmus : notice that the colour immediately changes to red. Dip this red-dened paper in a solution of soda : the blue colour is restored. Next add a few drops of litmus solution to the caustic soda in a large test-tube ; add the acid very carefully until the blue colour changes to a port-wine tint ; should this be overshoot, the mixture becomes red ; a very small quantity of soda must then be added ; this will bring the colour back to this intermediate tint. It may be that a single drop of either reagent changes the colour from full blue to red, or *vice versa* ; if so, dilute down some acid with four or five volumes of water, and add this drop by drop ; with care the port-wine tint may be thus hit. Now dip in some red and blue litmus paper : the colour of neither is changed ; neither free acid nor alkali is present ; the whole of each has united to form the salt, sodium chloride. Evaporate to dryness : cubical crystals form.

Experiment 70, in which dry hydrochloric acid is passed over manganese dioxide, shows that water is formed as a secondary product by the mutual action of an acid and base. An interesting modification of the experiment may be tried by substituting lead oxide or litharge (PbO) for the manganese dioxide. On applying heat to the bulb, the yellow litharge changes to white lead chloride, and abundance of water condenses in the second bulb according to the equation—



The names of acids are derived from those of their principal constituents by changing them into adjectives ending in *ic* ; thus, from sulphur we have sulphuric acid, and from nitrogen nitric acid. The hydracids are distinguished by the prefix *hydro* as hydrochloric acid. The names of the corresponding salts are derived from the same root by

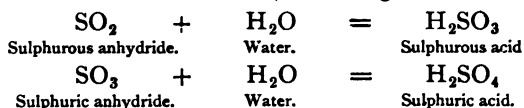
adding *ate* ; the salts of sulphuric and nitric acids are respectively sulphates and nitrates.

When an element forms two oxides, both of which unite with water to form acids, the acid containing the higher proportion of oxygen receives the name ending in *ic* ; for the other the termination *ous* is substituted. There are, for instance, two oxides of sulphur, SO_2 and SO_3 ; these are termed—

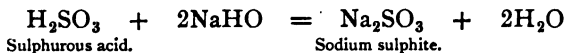
SO_2 Sulphurous anhydride

SO_3 Sulphuric anhydride.

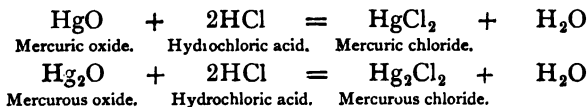
Both combine with water, becoming—



The salts of an acid whose name ends in *ous* have the termination *ite* :—



In describing the basic component of a salt, the simplest method is to mention the name as potassium sulphate. At times it is convenient to change this into the adjective form. When this is done, the same termination is used as is applied to the base itself ; thus, salts formed by the action of mercuric oxide (HgO) on acids are called mercuric salts ; those from mercurous oxide (Hg_2O), mercurous salts :—



The salts of the hydracids, being binary compounds, have names ending in *ide*.

Summary.

Names of binary compounds end in *ide* ; when the same elements form two, a separate name is given to each.

The most important compounds containing more than two elements are the acids ; the names of these are derived from the principal element.

CHAPTER XII.

ATOMICITY OR QUANTIVALENCE, AND BASICITY.

THE student already knows that the atom of chlorine combines with only one atom of hydrogen, while oxygen combines with two. From the following table he will see that certain elements may be classed together as combining with only one atom of hydrogen, those of another group combine with two atoms, those of a third combine with three, and those of the last with as many as four atoms. The chlorides may be similarly arranged into groups containing respectively one, two, three, and four atoms of chlorine. The corresponding oxides contain in each instance twice as high a proportion of the other element. Oxygen then may be said to possess double the combining power of chlorine.

HCl	H ₂ O	H ₃ N	H ₄ C
HB ₁	H ₂ S	H ₃ P	H ₄ Si
HI		H ₃ As	
ClH	Cl ₂ Ca	Cl ₃ B	Cl ₄ C
ClNa	Cl ₂ Ba	Cl ₃ Au	Cl ₄ Si
ClK	Cl ₂ Cu		Cl ₄ Pt
OH ₂	OCa	O ₃ B ₂	O ₂ C
ONa ₂	OBa	O ₃ Au ₂	O ₂ Si
OK ₂	OCu		O ₂ Pt

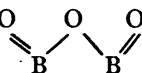
The terms *atomicity* and *quantivalence* are applied to numbers expressing the measure of this combining power. One series of elements is characterised by the atoms of its members never uniting with more than one atom of any other element; among them there are hydrogen, sodium, and chlorine. If we know the greatest number of atoms of either of these with which the atom of an element can combine, that number usually represents its atomicity.¹ Thus,

¹ This is not an invariable rule, as some elements unite with a higher proportion of oxygen than of hydrogen.

the atomicity of oxygen which combines with two atoms of hydrogen, is two, generally written in Roman numerals II. Gold unites with three atoms of chlorine, and accordingly has an atomicity of III. Carbon combines with four atoms of hydrogen ; its atomicity is, therefore, IV. We are not acquainted with the reason why certain atoms possess a greater combining power than others, any more than we know the exact nature of the tie that holds elements together in a compound, but in order to have some tangible idea of atomicity, it has been proposed to imagine that the atoms of various elements have a certain number of *bonds*, by means of which they can unite themselves to other atoms. Hydrogen is thus assumed to have but one of these bonds, and can attach itself at most to only one atom of any other element, while oxygen, having two bonds, is capable of combining with two of the single-bonded hydrogen atoms. This is graphically expressed by the use of lines to represent the bonds in the formulae ; thus $\text{H}-\text{Cl}$ shows at a glance that the two elements have each but one bond, and that these are united. Water is written on the same principle $\text{H}-\text{O}-\text{H}$. These are termed *graphic formulae*.

Elements, whose atomicity is one, are called monads ; whose atomicity is two, dyads ; three, triads ; four, tetrads ; five, pentads ; and six, hexads.

The atomicity (as far as it is known) of the elements is given in the table in Chapter III. ; that of the most important ones should be committed to memory. The formula of a body can in many instances be written from a knowledge of the atomicity of the constituent elements. The atomicity of any element usually represents the number of atoms of a monad with which it combines ; when two dyads unite, there is one atom of each in the molecule, as $\text{Ca}=\text{O}$ calcium oxide. Two atoms of a triad combine with three of a dyad ; thus, $\text{O}=\text{B}=\text{O}$, boric anhydride.



One atom of a tetrad combines with two atoms of a dyad ; as $O=C=O$, carbon dioxide. As a rule the number of active bonds of each element in a binary compound is equal. At times the same element forms two or more series of compounds in which its atomicity is different ; nitrogen, for instance, is in some compounds a monad, in others a triad, and others a pentad. But when an element has more than one atomicity, they are almost always expressed by either a series of even or of odd numbers, so that elements are sometimes simply classified into *artiads* having an even atomicity, and *perissads*, in which the atomicity is odd. It is probable that this results from the bonds of atoms uniting in pairs, and thus satisfying each other. Taking nitrogen as an example, this is represented graphically thus :—

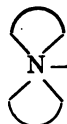
Pentad.



Triad.



Monad.

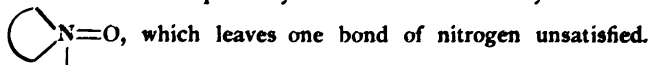


The highest atomicity an element possesses in any compound is termed the *absolute* atomicity. Where the element combines with a lower number of other atoms than is necessary to satisfy this, the number of its bonds entering into union is the *active* atomicity ; the number, which is inactive through mutual union, represents the *latent* atomicity.

It is difficult in some compounds to trace out the manner in which the bonds are disposed, and at first sight the laws of atomicity are apparently set at naught. Still, even with these seeming discrepancies, the composition of bodies is rendered much plainer by a knowledge of the atomicity of the elements of which they are composed.

The laws above enunciated are followed in the great majority of compound bodies which are known ; there are, however, a few exceptions, and these, although not numerous, are very decisive. For instance the compound of nitrogen and

oxygen known as nitric oxide cannot have its formula written graphically in conformity with the rules previously given. The molecule of that body contains 14 by weight of nitrogen and 16 of oxygen : this, therefore, must be expressed by NO. From a study of the great number of compounds of each of these gases, we must give them in almost all instances the absolute atomicities of V and II respectively. NO therefore can only be written



Some chemists explain this by assuming that the molecule of nitric oxide really contains two atoms of each element, and its formula, therefore, is N_2O_2 ; the graphic formula is then easily written $\text{O}=\text{N}\equiv\text{N}=\text{O}$. But this assumes that the molecule of this gas is double the size of that of hydrogen, thus making it an exception to the law of Avogadro. The student will remember that that law is based on the similar behaviour of different gases when subjected to varying temperatures and pressures; nitric oxide, however, acts exactly like all other gases, and, therefore, must be considered as equally with those obeying Avogadro's law; consequently, we must look on NO as its formula. Purely chemical considerations also point to its molecule being represented by the simple rather than the more complex expression.

Nevertheless, the almost universal obedience to the rule which states that the atomicity of an element is represented by either a series of even or odd numbers, causes us to look on it as much more than a coincidence; it is in all probability a *law*, the exceptions being ruled by a law within the law, of which we are as yet ignorant. The question of atomicity is a wide one, and its further consideration must be postponed until a more advanced stage of the student's studies.

The acids have a kind of atomicity of their own, depending on the number of atoms of hydrogen they contain which may be replaced by a base. Those containing but one atom of hydrogen are called *monobasic*, and those with two *dibasic*. A salt of a monad metal and monobasic acid contains but one atom of the metal and one molecule of the acid less the hydrogen. A few typical formulae are

given below, which will enable the student to write the formula of any salt he is likely to require in elementary chemistry.

Monad metal and monobasic acid	NaNO_3	sodium nitrate.
„ „ dibasic	Na_2SO_4	„ sulphate.
Dyad metal and monobasic	$\text{Ca}(\text{NO}_3)_2$	calcium nitrate.
„ „ dibasic	CaSO_4	„ sulphate.

The dibasic acids require two atoms of a monad metal to displace the whole of the hydrogen, while a dyad metal requires two molecules of a monobasic acid to form its salt. The formulae of such salts as $\text{Ca}(\text{NO}_3)_2$ are sometimes written CaN_2O_6 ; the former, however, shows more clearly its relation to nitric acid (HNO_3). The small 2 outside the bracket refers to the whole group within.

Dibasic acids may have a part only of their hydrogen replaced by a monad metal; they are then called hydric or acid salts. The acid sulphate of sodium is a salt with which the student is already familiar; it occurs as a secondary product in the preparation of hydrochloric acid, and has the formula NaHSO_4 .

CHAPTER XIII.

CARBON.

Symbol, C. Atomic Weight, 11.97. Specific gravity as diamond, 3.4.

OCCURRENCE.—This element occurs in nature both free and combined. Like oxygen, it is found in more forms than one. The various modifications present striking differences in appearance and properties from each other. The diamond and graphite are examples of native free carbon. In addition to these, carbon is an essential constituent of all organic compounds; that is, such substances as wood, flesh, bones, &c., and the numerous bodies which may be derived

from them. Coal, which is fossilised wood, must also be included among the carbonaceous bodies. It also largely occurs as carbonates, of which limestone is the most important.

PREPARATION.—By heating wood, coal or bones, in a closed vessel, carbon, in an impure state, may be obtained. Water, and volatile compounds of carbon with hydrogen and oxygen are driven off; the excess of carbon remains, together with the non-combustible portions of the wood or other body.

Experiment 74.—Fit up the apparatus shown in Fig. 7 with a combustion tube; place in it some chips of dry wood; fix the tube in the retort stand with the mouth slightly lower than the other end, so that any liquid which distils may not run back on the hot glass. Place a bottle for the collection of the gas, and apply heat to the wood: some water and a tarry liquid condense in the cooler part of the tube; an inflammable gas passes over into the jar. When the action ceases, a black mass remains of approximately the same shape as the original wood, and still retaining the grain and marks of woody structure: this body is charcoal.

This process of heating a body and causing its decomposition into gaseous and liquid products in part, which are collected, is termed 'destructive distillation.'

Charcoal is manufactured sometimes in this way, in large iron retorts, but more frequently by building a mass of wood faggots, covering them with peat and making an opening at the top and bottom. The pile is then fired, a portion only of the wood is allowed to burn, and its heat converts the remainder into charcoal.

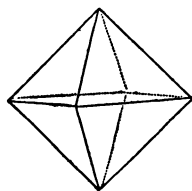
Coal is subjected to destructive distillation on the large scale for the manufacture of coal-gas; the carbon which remains in the retort is known as 'coke.' It is denser and harder than wood charcoal.

Bones, on being similarly treated, yield 'animal charcoal.' This, when finely ground, is called 'ivory black.'

A purer form of charcoal is obtained by burning turpentine, resin, or other substances rich in carbon. With a limited supply of air, the hydrogen burns, and the carbon being liberated, is deposited as soot in chambers arranged for its collection. In this way lampblack is made. It, however, still contains hydrogen, which is driven off by heating the lampblack intensely in a current of chlorine. Hydrochloric acid is formed, and carbon remains. The carbon obtained by the whole of these methods is amorphous: graphite and diamond are both crystalline. Graphite occasionally crystallizes out in small hexagonal plates, from the solution of carbon in fused cast iron. Chemists have long sought to obtain crystals of diamond by artificial means, but hitherto without much success. Hannay, in a paper recently read before the Royal Society, claims to have obtained diamonds by intensely heating certain carbon compounds with lithium. His results have not as yet been confirmed by experiments made by other chemists.

PROPERTIES.—The diamond is usually found in rounded pebbles, but sometimes occurs in well-developed crystals of octahedral form, or shapes closely allied to it. Fig. 27 is an illustration of an octahedron. The lozenge-shaped outline of this figure, when viewed in certain directions, is familiar to all under the name of 'diamond shaped.'

FIG. 27.



The diamond is the hardest substance known, scratching or cutting all other bodies. Small crystals set in a proper holder, are used by glaziers for cutting glass. When pure the diamond is perfectly transparent and colourless; it takes a very high polish. Its index of refraction is high (that is, a ray of light which enters it obliquely is bent very considerably). Owing to this fact much of the light undergoes total reflection, and this is one cause of its great brilliancy when cut and used as a gem. The diamond neither conducts electricity nor heat. It may be made red hot without

change ; but in the intense heat of the voltaic arc it swells up, becomes opaque, and is changed into a black coke-like mass, and acquires the power of conducting heat and electricity.

Graphite differs from the diamond in almost every characteristic. It occurs in compact masses, which appear to be more or less crystalline. The more perfect crystals occur as hexagonal plates. This crystalline shape is totally distinct from that of the diamond.¹ Graphite has a metallic lustre, and is of a leaden grey colour ; it has consequently also received the names plumbago and black-lead. It is very soft, and marks paper. The finer qualities are employed in the manufacture of black-lead pencils ; it has a peculiar greasy feel, and is sometimes employed for lessening the friction between two rubbing surfaces. After the metals, graphite is one of the best conductors of heat and electricity.

Amorphous carbon or charcoal possesses a remarkable property of absorbing gases and condensing them within its pores. Freshly burnt charcoal is in this way capable of absorbing about ninety volumes of ammonia. This property is demonstrated by experiment in the chapter on that gas. Owing to this peculiar property charcoal is a valuable antiseptic : it absorbs various putrefactive gases, and thus brings them into contact with oxygen, also condensed within it. Oxidation proceeds, and these gases, which are mostly composed of hydrogen and carbon, are changed into harmless and odourless compounds, viz., water and carbon dioxide.

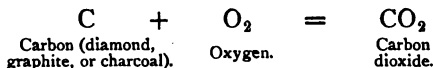
Charcoal also retains the colouring matter of liquids passed through it. Raw sugar is decolourised by being mixed in solution with animal charcoal and then filtered : the filtrate is found to be colourless.

Experiment 75.—Take some syrup of the brownest and coarsest sugar obtainable ; shake up in a test-tube with coarsely powdered animal charcoal ; allow the charcoal to subside, and

¹ Recent researches have caused some doubt as to whether or not it is truly crystalline.

then filter off : the sugar solution will be much lighter in colour. The colour of the original solution may, if necessary, be heightened by the addition of a little burnt sugar.

All forms of carbon are incapable of liquefaction or volatilization at the most intense heats at our command. They are all combustible ; the same weight of diamond, graphite and charcoal, yields the same amount of carbon dioxide when burned, thus establishing their chemical identity :—



The diamond may be burned by placing it on a connecting strip of platinum foil, between two copper wires, passing through the stopper of a gas jar filled with oxygen. The passage of a voltaic current raises the platinum to a white heat, the diamond burns away, leaving only a minute trace of ash.

Graphite may be burned more easily.

Experiment 76.—Fill a jar with oxygen ; place some powdered graphite in a clean deflagrating spoon ; ignite to a bright red heat over the foot blow-pipe, and quickly plunge into the gas. Notice a brightening of the glow on entering the oxygen. When the action is over, take out the spoon, add lime-water, and shake up : the lime-water becomes milky.

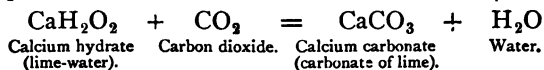
Charcoal burns in oxygen with readiness.

Experiment 77.—Place a piece of charcoal in the deflagrating spoon, kindle it, and introduce into a jar of oxygen : it burns brightly. Test the gas with lime-water, and note milkiness.

Lime-water is prepared by adding a small piece of lime to water, and shaking up in a stoppered bottle. When the excess of lime has settled to the bottom, the clear solution is poured off, and is ready for use.

Lime and carbon dioxide combine readily and produce an insoluble substance—carbonate of lime ; hence the milki-

ness. After a time this falls to the bottom as a white precipitate.



From this property lime-water is a most useful test for the presence of carbon dioxide. If the carbon dioxide is in considerable excess the precipitate will re-dissolve.

Bodies containing carbon also yield carbon dioxide when burned.

Experiment 78.—Light a taper, and place it in a jar of air ; when the light is extinguished, test with lime-water for carbon dioxide. Pour a few drops of methylated spirits in a deflagrating spoon ; light and place in a jar of air ; again test for carbon dioxide.

Burn a small jet of coal gas in a jar of air, using the same apparatus as was employed for the burning of hydrogen in chlorine ; as soon as the light goes out, remove the gas jet and test with lime-water.

In each case carbon dioxide is found to be present. Carbon and its compounds are so universally used as heat-producers that no fuel could be taken which did not give these reactions. Further than this, animal heat is also a result of the slow combustion of compounds of carbon. Air is drawn into the lungs, and there oxidizes certain constituents of the blood. Water and carbon dioxide are thus produced, and are exhaled continually from the lungs.

Experiment 79.—Breathe against any cold surface, as the outside of a bottle of water : it is covered with a film of dew, Breathe through a glass tube into some lime-water in a beaker ; it rapidly becomes milky.

Carbon dioxide is always present in the atmosphere as a result of these changes. Its presence may be detected by means of lime-water.

Experiment 80.—Partly fill an evaporating basin with lime-water, and let it remain exposed to the air for a few minutes : a thin film of carbonate of lime will have formed on the surface.

The functions of atmospheric carbon dioxide are treated more fully in Chapter XV.

Summary.

Carbon occurs in three forms : the diamond, graphite, and amorphous carbon as charcoal ; the two first are native, the third is obtained from certain organic bodies by heating them in closed vessels. The diamond is extremely hard ; graphite is soft and metallic-looking. Charcoal is used as a deodourizing and decolourizing agent. The whole three forms are combustible, producing carbon dioxide. This gas is detected by its turning lime-water milky. All bodies containing carbon produce carbon dioxide when burned ; carbon dioxide is also formed by animals breathing ; it is always present in air.

Laboratory Hints.

After experiment 73 clean the leading tube at once by passing water through it ; the tarry liquid is more difficultly removed after standing. Do not use any india-rubber tubing, but let the leading tube be entirely of glass.

In burning coal gas in a jar of air the jet must be removed as soon as the light goes out, because, if allowed to remain, the coal gas would displace the remaining air and carbon dioxide.

CHAPTER XIV.

OXIDES OF CARBON.

Two oxides of carbon are known :—

Carbon monoxide or carbonic oxide, CO.

Carbon dioxide or carbonic anhydride, CO₂.

The latter of these, being the most important, should be first studied.

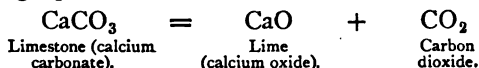
Carbon Dioxide. Formula, CO₂. Molecular weight, 43.89. Density, 21.84. Specific gravity, 1.527.

Graphic Formula, O=C=O.

OCCURRENCE.—The presence of carbon dioxide in the atmosphere is mentioned in the previous chapter ; it also

exists in vast quantities in combination with lime, in limestone, chalk marble, &c.

PREPARATION.—By the action of heat limestone may be decomposed into lime and carbon dioxide, according to the following equation :—

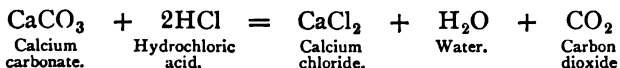


Enormous quantities of limestone are 'burned' in properly constructed furnaces called kilns, for the purpose of obtaining quicklime, that substance being used in making mortar. The student may separate the two on the small scale in the following manner :—

Experiment 81.—In a test-tube of hard glass tubing place a little powdered marble or chalk ; close the mouth of the tube loosely with the thumb, and heat strongly for about a minute over the foot blow-pipe. Keep the tube closed, and pour into another test-tube some lime-water ; the gas being heavier than air, pour it from the combustion tube into that containing the lime-water ; shake up : the lime-water becomes milky.

If the application of heat be continued, the whole of the carbon dioxide may be driven off ; but in the time mentioned a part only will probably be evolved.

A much readier method of separating the carbon dioxide from the base is by the addition of an acid, as hydrochloric. The following change ensues :—



Experiment 82.—Add a drop of hydrochloric acid to lime-water which has been rendered milky by carbon dioxide ; it immediately becomes clear. Add some hydrochloric acid to some fragments of marble in a test-tube : brisk effervescence occurs ; when over, pour the gas, and the gas only, into a second tube containing lime-water ; this, on shaking, becomes milky.

Experiment 83.—Prepare four jars of the gas in the following manner. Place some fragments of marble or limestone in

the flask arranged as for the preparation of hydrogen ; add a little water, and then some hydrochloric acid ; collect over water in the pneumatic trough.

PROPERTIES.—Carbon dioxide is a colourless gas. It has a faint, sweetish, acid taste and smell, which are best described as being those of a bottle of soda-water when opened (so-called soda-water is a solution of carbon dioxide in water under pressure).

At a pressure of 38·5 atmospheres this gas condenses to a liquid at 0° C. : it may also be liquefied at ordinary pressures by a temperature of -78° C. Liquid carbon dioxide is colourless and transparent : on being allowed to emerge in a stream from the vessel containing it, a part volatilises, and, in so doing, deprives the remainder of the heat necessary to maintain it in the liquid state ; it therefore freezes. Solid carbon dioxide obtained in this manner is a white, snow-like mass, which evaporates comparatively slowly.

At 15° C. the gas is soluble in about its own volume of water, whatever the pressure ; but as an increase of pressure increases the density of the gas, the *weight* absorbed is in direct proportion to the pressure to which the gas is subjected. Soda-water, lemonade, and other aerated beverages, are prepared by dissolving carbon dioxide in water, under the pressure of a force-pump. From the solubility of the gas in water, directions are frequently given for its collection by displacement, but the gas is obtained so readily in large quantity, that for most purposes it may as well be collected over water.

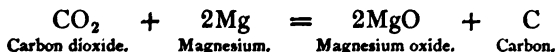
The weight of carbon dioxide permits many striking experiments to be performed with it.

Experiment 84.—Fill by downward displacement a bowl or some other vessel about eight inches diameter, and the same depth with the gas. Make a soap solution, and blow some bubbles ; detach them from the pipe used over the vessel of gas ; they will descend and float on the surface of the carbon dioxide.

This gas is generated in brewing. The vats remain full for some time after the liquor has been drawn off; and many deaths have occurred through men incautiously descending in them. The same danger exists from accumulations of the gas in mines. A lighted taper is instantly extinguished by the gas, which does not itself take fire.

Experiment 85.—Immerse a lighted taper in a jar of the gas: it is immediately extinguished. Take another jar of gas and pour it over a lighted taper; notice that it extinguishes it: this shows the greater density of carbon dioxide. Take care that any drops of water remaining in the jar do not fall on the taper.

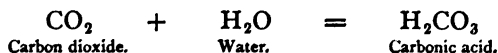
Several of the metals which have a great affinity for oxygen burn in the gas with the displacement of carbon. If a piece of brilliantly burning magnesium wire is introduced in the gas, it continues to burn; the fragments of magnesium oxide falling to the bottom are found mingled with carbon. On the jar being rinsed with a few drops of hydrochloric acid, the oxide dissolves, and the carbon is readily distinguished:—



Carbon dioxide possesses feebly acid properties when combined with water, and therefore is sometimes called carbonic anhydride.

Experiment 86.—Pour a little litmus solution into a jar of the gas, and shake up: the colour is changed to a port-wine tint, very different from that produced by the stronger acids.

The solution of carbon dioxide in water is undoubtedly a true acid.



It is, however, very unstable, and has never been separated from an excess of water. The gas is expelled entirely by boiling the water, or by freezing it.

Being a dibasic acid it forms a double series of salts, one of which is normal, the other acid. Thus we have sodium carbonate Na_2CO_3 , and sodium bicarbonate, or acid carbonate of sodium, NaHCO_3 . The attraction of carbon dioxide for bases has been already utilised by the student in his tests for that gas by lime-water. Lime absorbs carbon dioxide slowly from the atmosphere; hence, pieces of old mortar invariably contain it. It aids in 'setting' the mortar, which becomes harder with age.

Experiment 87.—Place some fragments of old mortar in a test-tube; pour on them some hydrochloric acid: notice the effervescence; when over, pour the gas into another test-tube containing lime-water: it is rendered milky.

The carbonates are an important series of salts; with the exception of those of the alkalies, they are insoluble in water. They are readily decomposed by almost any acid, with the liberation of carbon dioxide.

Several of the bicarbonates are soluble, the corresponding carbonates being insoluble. That of lime is an interesting and important example.

Experiment 88.—Boil some *hard* water from springs in chalk or limestone formations (if obtainable) in a small flask or beaker for about a quarter of an hour; at the expiration of that time, notice that the water has become slightly turbid by the separation of calcium carbonate.

The bicarbonate has been decomposed by heat, the carbon dioxide evolved, and the insoluble carbonate precipitated:—



The same experiment may be tried in another manner in which the formation of the bicarbonate may also be noticed.

Experiment 89.—Fit to the carbon dioxide apparatus a small wash-bottle with water; pass the washed gas for some minutes

into some lime-water in a beaker : a precipitate at first forms, and is after a while redissolved. Then boil for some minutes : calcium carbonate is again deposited.

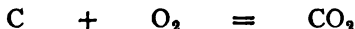
Carbon dioxide is injurious when present in air in large quantity ; all rooms should, therefore, have ample means of ventilation. Nine sleeping rooms out of ten are insufficiently furnished in this respect ; a room should never be used for sleeping purposes without at least the register of the stove open.

Carbon dioxide contains its own volume of oxygen ; consequently, carbon may be burned in that gas without its undergoing any change of volume. Its composition by weight is ascertained by burning a weighed amount of carbon in oxygen, and collecting and weighing the resulting carbon dioxide.

Carbon monoxide. Formula, CO. Molecular weight, 27.93. Density, 13.96. Specific gravity, 0.967.

Graphic Formula,  **C=O.**

OCCURRENCE.—Everyone is familiar with the appearance of a coke or charcoal fire, or of a coal fire which has burned perfectly clear and smokeless ; the whole mass glows with a bright red heat, and hovering over the top are lambent blue flames : the origin of these may be traced in this way : in the lower parts of the grate, where air enters the fire, carbon dioxide is formed according to the following equation :—



This makes its way upwards through the red-hot carbon and becomes changed by reduction to carbon monoxide, and thus an inflammable gas is produced. The same effect is produced in the following manner :—

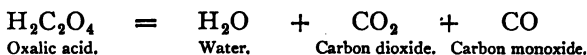
Experiment 90.—Loosely fill an iron tube with fragments of charcoal ; fit to each end corks with pieces of quill tube passed through ; place it in a furnace, and raise to a red heat.

Pass a slow current of carbon dioxide through the tube ; light the gas as it emerges : it burns with the same blue flame as is seen playing over the coke or charcoal fire.

Evidently, then, the gas is changed ; for carbon dioxide is non-inflammable. The change is thus represented :—



PREPARATION.—The gas is most conveniently prepared by heating certain organic compounds with concentrated sulphuric acid. This body has a very great attraction for water, in virtue of which it decomposes many substances containing hydrogen and oxygen, and assimilates the water : the remaining atoms re-arrange themselves into whatever other compounds are possible. Oxalic acid, when thus treated, is split up into water, carbon dioxide, and carbon monoxide :—



Equal volumes of carbon monoxide and dioxide are thus produced.

Experiment 91.—Place in an eight-ounce flask, fitted with either thistle funnel and leading tube, or with a leading tube only, half an ounce of oxalic acid (crystallized), and an ounce of concentrated sulphuric acid. Gently heat the mixture, and after the expulsion of air, fill three jars with the gas over water in the pneumatic trough. As this gas is very poisonous, it should be prepared in the stink-cupboard.

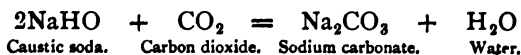
Experiment 92.—Place a light to one jar : notice that the gas burns with a blue flame.

Experiment 93.—Add some lime-water to a second, and observe that, on being shaken, it becomes milky.

Experiment 94.—Prepare a solution of crude caustic soda, and pour it into a beaker sufficiently large to hold a jar and the glass plate. Invert a third jar in this solution ; hold the glass plate to the bottom of the beaker with a glass rod ; and thus remove it from the mouth of the jar. Let it stand in the

soda for some time : the liquid slowly rises through the absorption of the carbon dioxide, until the jar is half-filled. The quantity of soda solution to be taken should be roughly estimated from the size of the jar.

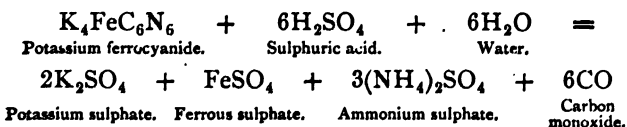
In this last experiment the soda and carbon dioxide unite and produce sodium carbonate :—



Carbon monoxide may be prepared free from the dioxide by the use of formic instead of oxalic acid. The following reaction then takes place :—



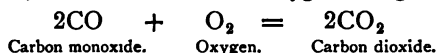
Another method is to heat potassium ferrocyanide (yellow prussiate of potash) with sulphuric acid ; the change occurring is complicated :—



Experiment 95.—Take a sixteen, or preferably a thirty-two ounce flask, fitted with thistle funnel and leading tube. Insert, in lumps, a quarter of an ounce of commercial ferrocyanide, and about two ounces of sulphuric acid. Get three jars ready filled with water and inverted in the pneumatic trough. Fix the flask in the retort stand with the end of the leading-tube in the trough ; apply heat carefully. As soon as the gas begins to be evolved, remove the flame, as the action continues with extreme rapidity. When the whole of the air is expelled, fill the three jars with gas. The end of the thistle funnel should be pushed down as near as possible to the bottom of the flask without touching. Sometimes, through lack of sufficient precautions, the gas is produced so violently that the pressure forces the boiling acid up through the funnel ; should this be the case, remove the light, take the delivery tube out of the water, and stand out of the reach of splashes of falling acid.

Throw whiting on any which is spilled on the working bench, and then wipe off with an old duster.

PROPERTIES.—Carbon monoxide is a colourless gas ; it has a slight oppressive odour, and is extremely poisonous, producing a painful headache even when present in small quantities in air. It is but slightly soluble in water : 100 volumes dissolve 2.434 volumes of the gas at 15° C. It liquefies only under very great cold and pressure. Carbon monoxide is inflammable and a non-supporter of combustion ; when burned its own volume of carbon dioxide is produced ; half of its volume of oxygen being required:—



Experiment 96.—Immerse a lighted taper in a jar of the gas : it is extinguished, but the gas burns with a blue flame, as when made from oxalic acid.

This gas is devoid of acid properties, and consequently is without action on lime-water.

Experiment 97.—Add some lime-water to a jar of the gas, and shake up : no turbidity is produced. In flame the gas, replace the plate, and then again shake : the lime-water becomes milky through the presence of carbon dioxide.

The composition of carbon monoxide is determined by explosion with excess of oxygen in the eudiometer ; the volume of the monoxide and of the oxygen are observed. After the explosion, potassium hydrate is introduced : the diminution in volume represents the carbon dioxide formed which is absorbed. From these data the composition of the monoxide is readily deduced.

Summary.

There are two oxides of carbon—carbon monoxide and dioxide.

Carbon dioxide occurs in the atmosphere and in combination with lime in limestone ; may be prepared by heating limestone, or more conveniently by the action of an acid, as hydrochloric. It is a colourless gas, with a very faint odour and taste ; may

be condensed by pressure ; is soluble in water ; is half as heavy again as air—hence, may be poured from vessel to vessel ; remains for a long time in the bottom of brewers' vats, &c.; is non-inflammable and a non-supporter of combustion of most substances, but allows certain metals, as potassium and magnesium, to burn in it. The solution of the gas is slightly acid to litmus ; it forms a series of important salts, which are readily decomposed by a stronger acid. All the carbonates are insoluble in water except those of the alkalies ; certain others form soluble bicarbonates with excess of carbon dioxide : lime exists in this form in most hard waters. Carbon dioxide contains its own volume of oxygen.

Carbon monoxide is formed in the burning of coke by the deoxidation of carbon dioxide ; the same change occurs if carbon dioxide is passed over red-hot charcoal in an iron tube. The gas is more generally prepared by the action of sulphuric acid on some organic bodies, as oxalic or formic acids, or potassium ferrocyanide.

Carbon monoxide is a colourless gas with a faint oppressive odour ; is very poisonous ; slightly soluble in water. It is inflammable and a non-supporter of combustion ; it is devoid of acid properties. Its composition is ascertained by explosion in the eudiometer.

Laboratory Hints.

A solution of crude caustic soda is conveniently kept for use in the laboratory ; the soda is very cheap, and the same solution can be used several times for such an experiment as No. 94. The solution which has been once used should not be replaced in the same bottle.

CHAPTER XV.

NITROGEN AND THE ATMOSPHERE.

Symbol, N. Atomic weight, 14.01. Density, 14.01. Specific gravity, 0.971. Molecular weight, 28.02. Molecular volume, $\left[\frac{1}{1} \right]$.

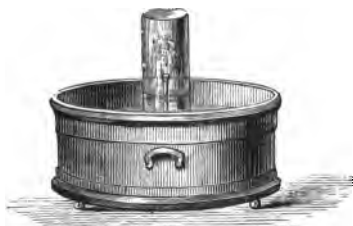
NITROGEN exists in the free state in the atmosphere, in

combination with oxygen and metals in certain native nitrates, and also is an essential constituent of many organic compounds.

PREPARATION.—There are several methods of preparing this gas, based on the removal of oxygen from the air by bodies having an affinity for that element : but in order that nitrogen only shall remain, it is necessary that the substance used be such that the resulting body can be easily separated from the gas. Phosphorus is very convenient for this purpose, as the solid pentoxide produced is very soluble in water.

Experiment 98.—Procure an upright deflagrating spoon on

FIG 28.



stand ; place in it a small piece of dried phosphorus ; stand the spoon in the pneumatic trough with water ; ignite the phosphorus and immediately invert over it a gas jar : at first a few bubbles of air escape, owing to their being expanded by heat ; the phosphorus soon ceases

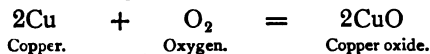
to burn ; the fumes are dissolved by the water, and rather less than four-fifths of the original volume of gas remains : the loss is mostly oxygen, but there is in addition that resulting from the escape due to expansion.

A more accurate measurement may be made by removing the oxygen by the slow oxidation of phosphorus, which goes on at ordinary temperatures.

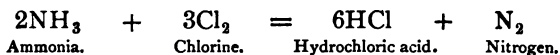
Experiment 99.—Take a piece of phosphorus about an inch long, and scrape off the oxide from it, holding it all the while under water ; fix this in the spoon, and proceed exactly as before, except that the phosphorus is not lighted. If only a small piece is used, the phosphorus pentoxide first formed absorbs water, and so the whole piece, if it lie below the level of the top of the spoon, may be covered and prevented from undergoing further oxidation. At the end of from two or three days to a week, observe and mark how far the water has ascended.

Ascertain what proportion the whole contents of the jar bears to the gas remaining ; this is easily done by filling the jar with water and pouring it out into the graduated measure ; then in the same way measuring its contents when filled to the mark indicating the absorption of oxygen. As the combination goes on in this case without any sudden heat, there is no loss by expansion.

The oxygen may also be removed by the action of metallic copper. If an iron tube be filled with copper turnings, and made red-hot in a furnace, the copper immediately combines with the oxygen of any air which may be passed through, leaving the nitrogen—



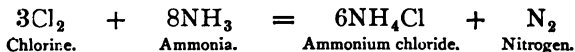
There are several other methods of preparing nitrogen which are interesting from a theoretical point of view. For instance, the gas is evolved by passing chlorine into an excess of ammonia. The hydrogen and chlorine unite, and nitrogen is liberated.



A secondary reaction goes on between the acid formed and the excess of ammonia, thus—



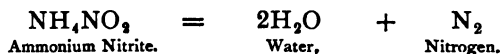
The two equations may be grouped into one, thus—



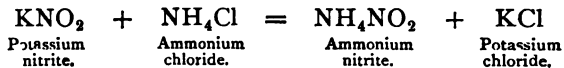
Experiment 100.—Prepare a flask for the evolution of chlorine ; arrange a second flask as a wash-bottle with the delivery tube very wide, and place in it two or three ounces of strongest solution of ammonia ; connect to the chlorine flask, and to the delivery tube of the wash-bottle attach a large diameter piece of tubing leading into the pneumatic trough. Heat the chlorine mixture : as each bubble passes into the ammonia, dense white fumes of ammonium chloride are produced ; a wide

leading tube is used, because a narrow one might be choked by accumulation of this salt. Considerable heat is evolved, and the action is so intense that flashes of light accompany the combination of the chlorine and hydrogen. Collect one small jar only of the nitrogen which passes over, and apply a lighted taper: the light is extinguished, and the gas does not take fire. Unless strict attention be paid to the laboratory hints at the end of the chapter, this experiment becomes dangerous.

Another interesting method of preparing nitrogen is by the action of heat on the salt known as ammonium nitrite. This contains oxygen and hydrogen in the proportions necessary to form water: they combine, and nitrogen is liberated.



It is usual to prepare the ammonium nitrite at the time of the experiment, that body being somewhat unstable. Ammonium chloride being added to potassium nitrite, the following decomposition takes place:—



Experiment 101.—Take a four-ounce flask fitted with a cork, through which passes a single leading tube; put in about a quarter of an ounce of potassium nitrite and an ounce of saturated solution of ammonium chloride in water; arrange a jar for the collection of the gas, and apply heat; the nitrogen comes over readily. The potassium chloride remains unaltered in the flask. Again test the gas by placing in it a lighted taper; also introduce some litmus paper; notice that the gas is neutral.

PROPERTIES.—Nitrogen differs remarkably in properties from oxygen, with which it is associated in the atmosphere. The one is specially characterised by its great chemical activity; the other is most inactive. It is a colourless, odourless, neutral, and tasteless gas, which is neither inflammable, nor a supporter of combustion. It is not poisonous, but is unable to support life. Animals placed in it speedily die through suffocation. By the action of intense heat it

may be caused to combine with oxygen, to form a ruddy-coloured gas, which, by uniting with more oxygen and water, produces nitric acid. Small quantities of nitric acid are thus produced in the atmosphere by lightning discharges. The effect may be imitated on the small scale by passing a series of sparks from an induction coil through moist air contained in a small glass globe. The air assumes a faint red tint, and litmus paper placed in the globe shows that it possesses an acid reaction.

Experiment 102.—Procure a globe properly prepared with platinum wires through the sides; introduce a piece of moistened blue litmus paper; cork up the vessel, and pass through it for about ten minutes a current of sparks from the induction coil; notice that the effects described above are produced.

Nitrogen is but slightly soluble in water: 100 volumes at 0° C. dissolve but 1·48 volumes of this gas.

THE ATMOSPHERE.—This gaseous body, which envelops the earth, is of vast importance to us who live and breathe in it. Its composition has been made the subject of many careful experiments, which show it to be a mixture of nitrogen and oxygen, approximately in the proportion of four to one. A rough kind of analysis of air has been already made by the student, the oxygen being removed by phosphorus. In addition to these two elements there are also present varying quantities of aqueous vapour, carbon dioxide, ammonia, nitric acid, and traces of other bodies. Its average composition is shown in the following table:—

Oxygen	. . . . .	20·61
Nitrogen	. . . . .	77·95
Carbon dioxide	. . . . .	0·04
Aqueous vapour	. . . . .	1·40
Nitric acid	. . . . .	} Traces
Ammonia	
Carburetted hydrogen	
In towns	{ Sulphuretted hydrogen	}
	{ Sulphur dioxide	

The proportion of nitrogen to oxygen in air is remarkably constant, but little variation from the above being found in air collected in the most varied localities. The results of careful analyses of air, freed from carbon dioxide and aqueous vapour, give the following average composition :—

	By measure.	By weight.
Nitrogen	79·19	76·99
Oxygen	20·81	23·01
	<u>100·00</u>	<u>100·00</u>

The composition by volume may be determined by using a eudiometer tube similar to that used in experiment 50, Fig. 18, for showing the production of water by the union of oxygen and hydrogen. A measured quantity of air is placed in the eudiometer, and hydrogen added in excess of that necessary to combine with the whole of the oxygen present ; on the passage of a spark, union of the hydrogen and oxygen is effected, and on the gas regaining its original temperature, the volume is found to be much less. As water is composed of two volumes of hydrogen to one of oxygen, the amount of oxygen present in the gaseous mixture is one-third of the diminution observed. The eudiometer employed for this purpose should be graduated. Supposing that 10 c.c. of air have been introduced and 5 c.c. of hydrogen added, after the explosion the volume will be found to be reduced from 15 to about 9 c.c. ; 10 c.c. of air therefore contain approximately $\frac{6}{3}=2$ c.c. of oxygen, the more accurate figures being those given above.

The composition by weight is ascertained by passing air over red-hot copper, due precautions being taken to avoid error. The copper is placed in a piece of difficultly fusible glass tubing, with which it is weighed ; an exhausted receiver is also weighed and attached to one end of this tube ; the

other is connected with U-tubes filled with caustic potash and sulphuric acid respectively, for the purpose of removing carbon dioxide and water. The glass tubing is raised to red heat, the stop-cock of the receiver is opened, and a slow current of air passes over the copper ; its oxygen is removed, and nitrogen only passes into the empty receiver. The gain in weight of the copper represents the weight of oxygen, and that of the receiver the weight of nitrogen.

That air is a mixture and not a compound may be proved in many ways : in the first place, the oxygen and nitrogen are not present in any simple multiple of their atomic weights, which is a necessity in all compounds. Air also differs remarkably from those compounds of the two elements with which chemists are acquainted. If a mixture be made of nitrogen and oxygen in the proportion in which they exist in air, no alteration of volume takes place, neither is there any increase of temperature ; the mixture exhibits all the properties of air.

Experiment 103.—Mix in a gas jar in the pneumatic trough four volumes of nitrogen with one of oxygen ; introduce a lighted taper : it continues to burn exactly the same as in air.

The most conclusive evidence of their being mixed, and not combined, is that they may be separated by the action of water as a solvent. Oxygen is more soluble than nitrogen, and if water, which has been previously freed from gases by boiling, be shaken up with air, and then again boiled, the expelled gas is found on analysis to be much richer in oxygen than was the air ; the oxygen amounting to about 34 per cent. of the dissolved gases.

It has already in Chapter XIII. been pointed out that carbon dioxide is present in air, and that the breathing of animals and the burning of carbonaceous bodies are continually supplying this gas : although this operation is proceeding without intermission, the quantity of carbon dioxide present in the atmosphere shows to the most refined modes

of analysis no increase. Its amount varies between 3 and 6 parts in 10,000 according to the locality where, and time when, the gas is collected. This quantity, though small, is of vast importance to the vegetable kingdom, as it is the source from which all organic carbon is derived in nature. Animals can only assimilate carbon from previously existing organic compounds. Vegetables decompose carbon dioxide, using the carbon in the formation of their tissues, and liberating the oxygen in the free state. The effects, therefore, of animal and vegetable life on the atmosphere are opposite in character, the one removes oxygen and returns carbon dioxide, the other decomposes this compound, and again yields oxygen to the air (this return action is, however, partially balanced by the ordinary progress of decay); these two processes going on simultaneously keep the proportion of carbon dioxide in air within constant limits. The decomposition of certain rock-forming minerals, as felspar, by the action of the carbon dioxide of the atmosphere, which combines with the bases that they contain, is another important drain on the amount of that gas present in air.

The amount of aqueous vapour which the atmosphere contains varies considerably; but it is always present in more or less quantity. Its presence may be demonstrated by bringing a vessel of ice-cold water into a room: the aqueous vapour condenses on the outside as a film of moisture.

Ammonia is only found in air in minute traces. These, however, are important, as from them plants obtain a great proportion of their nitrogen.

Summary.

Nitrogen exists in the free state in the atmosphere; and is also found in nitrates and different organic bodies. It is prepared either by the removal of oxygen from the air by the action of phosphorus or copper; or by the decomposition of bodies containing nitrogen, as ammonium nitrate and ammonia. Nitrogen is a colourless, odourless, and tasteless gas; is neither inflammable nor a supporter of combustion; is neutral to litmus

Functions of Atmospheric Carbon Dioxide. 131

paper ; by great heat may be made to combine with oxygen forming acid compounds.

The atmosphere is a mixture of nitrogen and oxygen, with small quantities of other compounds present. Its composition is determined by explosion with hydrogen and other methods. Air is a mixture, proved by different solubility of the two gases in water.

Carbon dioxide is produced by the breathing of animals and burning of substances containing carbon. The same gas is removed by the action of vegetable life and oxygen restored to the air.

The ammonia present in air supplies nitrogen to plants.

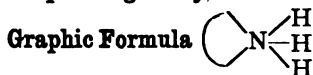
Laboratory Hints.

In preparing nitrogen by the action of chlorine on ammonia, strict attention must be paid to the directions *always to have excess of ammonia* : see accordingly that the solution used is the strongest, of specific gravity 0.88, and not the dilute solution employed in the laboratory for analytical purposes. Prepare but one jar of the gas by this method. These precautions are necessary because with excess of chlorine a most violently explosive compound of nitrogen and chlorine is formed. The wide leading tube is also an essential. The glass globe with platinum wires passed through, used in experiment 102, should be obtained from the general apparatus of the laboratory ; they can be bought of any apparatus dealer ; the form sold is, however, somewhat fragile, and not well suited for the rough usage of a laboratory. One may be easily prepared by taking a three or four ounce wide-mouthed bottle, fitting it with a cork through which is passed two pieces of quill glass tubing in which platinum wires are fused. The ends of the wires should be about an eighth of an inch apart, and reach to the middle of the bottle : the glass tubes are to be filled with mercury ; the connection with the coil is made by dipping the *clean* ends of the leading wires underneath its surface. The cork should be soaked in melted paraffin. The apparatus as thus constructed bears some resemblance to that described for the electrolysis of water in experiment 47, Fig. 14. Remember when the cork is taken out of the bottle to so place it that the mercury does not run out of the tubes.

CHAPTER XVI.

AMMONIA.

Formula, NH_3 . Molecular weight, 17.01. Density, 8.5. Specific gravity, 0.59.



THIS, the only compound of nitrogen and hydrogen, known in the free state, exists in small quantities in the atmosphere, and also in rain-water. It is probably a resultant product of the oxidation of different organic substances in the presence of moist air. The oxygen of the water acts as the oxidising agent, and the nascent hydrogen combines with nitrogen to form small quantities of ammonia. It is produced in considerable quantity in the decomposition of animal and vegetable bodies which contain nitrogen. The urine and excreta of animals contain refuse nitrogenous matter. This after a time becomes changed into ammonia, and thus causes these substances to be such valuable manures, as plants are incapable of assimilating nitrogen while free, but are able to do so when that element is presented to them as ammonia.

The name ammonia is derived from that of Jupiter Ammon, because near a temple dedicated to him the Arabs extracted one of its compounds from camel's dung. If quills, horn, hair, &c., be heated in a closed vessel, various gases are evolved, among which ammonia is always present.

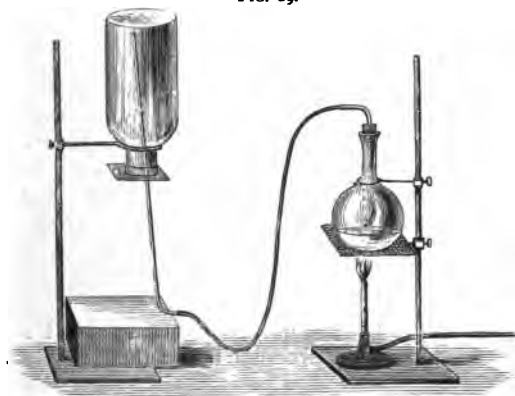
Experiment 104.—Heat in a test-tube some hair or quill cuttings; place a piece of red litmus paper in the condensed moisture in the upper part of the tube: it is turned blue.

Coal contains about 2 per cent. of nitrogen, and in like manner evolves ammonia when heated. As this substance

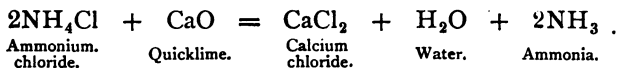
is subjected to destructive distillation on the large scale in the manufacture of coal gas, it affords a cheap and plentiful source of ammonia. The ammonia passes over with the gas, and is dissolved by the condensed moisture. This constitutes the gas or ammoniacal liquor of the works. From this ammoniacal salts are prepared by the addition of acids.

PREPARATION.—Ammonia may be prepared from any of these salts by heating with a stronger base, as lime or soda. Of these lime is preferred, because of its cheapness. If

FIG. 29.



ammonium chloride and lime be heated together, the following reaction takes place :—



Experiment 105.—Fit to an eight-ounce flask a cork with single delivery tube, to which is attached, by means of a moderately long piece of india-rubber tubing, a glass tube about a foot in length. The flask, tubing, and all other apparatus must be perfectly dry. Dry separately some powdered lime and ammonium chloride (sal-ammoniac): the lime may be dried by simply heating in a sand-bath; to dry the ammonium chloride, place it

in an evaporating basin and heat gently either in the sand-bath or on a piece of wire gauze over the Bunsen flame turned down very small ; the heat must not be sufficient to cause any fumes to be evolved. This may be set to dry before preparing the flask. They must be allowed to cool ; then take about half an ounce of the ammonium chloride and an ounce of the lime. The bath sand being cold, mix intimately in the mortar the chloride and about two-thirds of the lime ; notice that ammonia is given off, by its smell ; pour the mixture into the flask, and then add the remaining lime in a layer over the top. Fix the flask in the retort stand with a piece of gauze underneath, arrange the leading tube upright so that gas may be collected by upward displacement ; invert a dry gas bottle over the tube, the end of which must reach right up to the top. Fig. 29 shows the whole arrangement ; the gas bottle is most conveniently held on the ring of a retort stand. Apply a gentle heat to the flask : the gas is evolved readily. To test when the jar is full, hold a piece of reddened litmus paper outside the bottle just above the mouth : it will be turned blue ; draw the tube out of the bottle, lift it from the ring and quickly place on the cover. Three jars of gas should be in this way collected.

Experiment 106.—Then place the end of the delivery tube in a little distilled water in a beaker ; notice that the whole of the gas is absorbed ; in two or three minutes remove the tube, and withdraw the Bunsen from the flask : the liquid smells of the gas ; to some litmus solution in a test-tube add a drop of sulphuric or hydrochloric acid so as to just redden it ; to this add the ammonia solution : the blue colour is restored.

PROPERTIES.—Ammonia is a colourless gas with a most pungent and characteristic odour, which is pleasant when the gas is mixed with air ; but in the undiluted state the gas acts as a powerful irritant, bringing tears to the eyes, and if accidentally inhaled, even in small quantities, destroys the surface of the mucous membrane of the mouth, and may produce even fatal effects by its action on the lungs. The solution in water has a burning and disagreeable taste. The gas may be condensed to a liquid by a temperature of -50°C. , or a pressure of about 7 atmospheres at 15°C. Like other

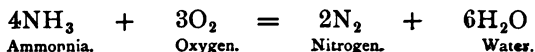
liquefied gases, liquid ammonia is very volatile, producing great cold in evaporating. This property causes it to be largely used in the manufacture of artificial ice. The gas is remarkably soluble in water, which dissolves at 0° C. 1050 times its volume of the gas; at 15° C., 727 volumes. The concentrated solution readily evolves gas on being heated, and may frequently be used with advantage as a source of the gas. At ordinary temperatures the solution gives off gas; hence its pungent odour. A solution of hydrochloric acid in water has a higher specific gravity than water, while that of ammonia is lower. The concentrated solution at 15° C. has a specific gravity of 0.880.

Experiment 107.—Place the mouth of one of the jars of gas under water and remove the glass plate: the water rushes up with violence and fills the jar.

It has been before mentioned that charcoal possesses the property of absorbing gases: ammonia is a striking example. Freshly burned charcoal absorbs about 90 volumes of this gas.

Experiment 108.—Take a dry six-inch test-tube, fill it with mercury in a mercury trough, and fix in a retort stand with the mouth under the surface. In a clean four-ounce flask place about an ounce of concentrated ammonia solution, fit to it a cork with single delivery tube, leading into the mercury trough, fix the flask in the retort stand, and apply a gentle heat, gas comes over almost immediately; wait until the air is all expelled, and then fill the test-tube with gas. Select a piece of charcoal of a size that will easily go into the tube; heat it in the Bunsen, and then by means of the tongs introduce it through the mercury into the gas; it rapidly absorbs it, and the mercury rises to the top of the tube.

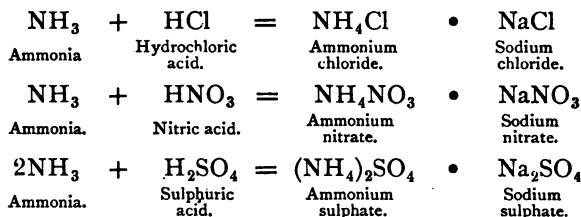
Ammonia is a non-supporter of combustion, and non-inflammable at ordinary temperatures; but when heated, it takes fire and burns with a greenish flame: water is produced, and nitrogen set free.



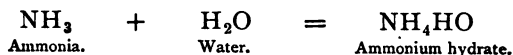
Experiment 109.—Place a lighted taper in a jar of the gas, the taper goes out, but just before doing so the flame slightly enlarges and becomes of a green colour.

Experiment 110.—Place in the furnace an iron tube fitted with corks and pieces of quill tube at each end : when the tube is red hot connect to it the four-ounce flask containing ammonia solution ; apply heat, and light the gas as it emerges from the iron tube : it burns with a green flame.

It has already been seen by experiment that ammonia restores the blue colour to litmus. It neutralises the strongest acids, and forms a well-marked and most important series of salts. The composition of some of these is thus shown :—



The salts of sodium are also written in a separate column for the sake of comparison. It will be seen that the group NH_4 and sodium occupy corresponding places. Further, this group may be expelled from one chemical compound and caused to enter another without decomposition. Because it thus behaves in so many compounds as though it were an element, it has received a name *ammonium*, for which the symbol Am is sometimes used: such a group of elements is termed a *compound radical*. Ammonium chloride is written either NH_4Cl or Am Cl. Ammonium, however, cannot be isolated, but immediately splits up into ammonia and free hydrogen. The solution of ammonia in water is sometimes conveniently represented as a hydrate of ammonium, thus—



This, again, is analogous in composition to sodium hydrate, NaHO . The principle of the preparation of ammonia is simply, therefore, to displace it from a salt by the action of a stronger and non-volatile base, as lime. The action is similar to that in which a volatile acid, as hydrochloric, is displaced by a less volatile and more powerful acid, as sulphuric.

The salts of ammonium are formed, as shown by equations, by the direct union of the acid with gaseous ammonia.

Experiment 111.—Fill a bottle with hydrochloric acid gas, place it over the remaining bottle of ammonia, remove the plates, bringing the mouths of the bottles together; a dense white cloud of ammonium chloride is formed; the bottles get sensibly warm to the hand.

Salts of ammonia with volatile acids may in some cases be sublimed unchanged, as with ammonium chloride. Others are decomposed, as ammonium nitrate: those with non-volatile acids, as ammonium phosphate, are decomposed, the acid remains, and free ammonia is evolved.

Experiment 112.—Heat a little ammonium chloride in a test-tube; the salt, if pure, entirely sublimes, and recondenses in the upper part of the tube. In a second tube heat some ammonium phosphate: free ammonia is evolved and phosphoric acid remains.

The composition of ammonia by volume may be ascertained by passing a series of electric sparks through the gas in an eudiometer. Its volume is doubled; two molecules of ammonia producing one molecule of nitrogen, and three of hydrogen. The quantity of hydrogen is determined by adding excess of oxygen, and exploding. It amounts to two-thirds of the diminution. The excess of oxygen is then removed by adding pyrogallic acid, which absorbs it; and the residual gas is nitrogen.

Summary.

Ammonia exists in traces in the atmosphere; is formed by

the decomposition of nitrogenous organic matter : is manufactured from the watery distillate of the gasworks, by neutralizing with acid and subsequently treating the salt produced with lime and heating.

Ammonia is a colourless gas, with characteristic odour, may be liquefied by pressure or cold ; is very soluble in water, and is also absorbed in large quantities by charcoal. The gas is a non-supporter of combustion, and is non-inflammable at ordinary temperatures ; but when heated burns with a greenish flame. It is alkaline to litmus paper, and forms with acids a series of salts, in which NH_4 occupies the place of a monad metal. This group has received the name ammonium and symbol Am ; does not exist in the free state, but breaks up into ammonia and hydrogen. Ammonium salts are volatile if the acid be so ; those with a fixed acid are decomposed ; the acid remains and ammonia is evolved.

The composition is determined by decomposing the gas by electricity and estimating the hydrogen and nitrogen.

Laboratory Hints.

In preparing ammonia from the chloride and lime, unless both are dried, there is a danger of breaking the flask by water condensing in the upper parts and trickling down on the hot glass. It is a good plan to place two pieces of gauze under the flask, and to use a rose burner if you have one ; otherwise keep the flame small. When collecting a gas by displacement, it is advisable to have a piece of cardboard closing the mouth of the jar, with a slit through it for the leading tube ; this is kept on the mouth until the glass plate is exchanged for it.

When the end of the leading tube is placed in water, watch carefully to see that the gas is not absorbed so rapidly as to cause the water to rise in the tube ; should it have a tendency to do so, increase the heat, and, if necessary, take away the beaker of water, and draw the cork from the flask. In any case remove the beaker *before* the flame.

There is a difficulty in filling jars in the mercury trough through not being able to see the end of the leading tube ; this should be bent up at an acute angle, and may then be hooked into the mouth of the tube. A tube of stouter glass than that of the test-tube is much better, and may be made by drawing out a piece of glass tubing.

CHAPTER XVII.

OXIDES AND ACIDS OF NITROGEN.

THERE are five compounds of nitrogen and oxygen known, two of which, by union with water, form acids ; their names and composition are :—

Nitrogen monoxide, or nitrous oxide, N_2O

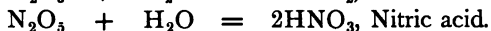
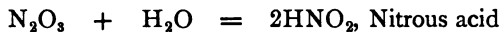
Nitrogen dioxide, or nitric oxide, NO (or N_2O_2)

Nitrogen trioxide, or nitrous anhydride, N_2O_3

Nitrogen tetroxide, or nitric peroxide, NO_2 (or N_2O_4)

Nitrogen pentoxide, or nitric anhydride, N_2O_5

By the action of water we have—



This series of compounds is interesting because it affords such a striking illustration of the law of multiple proportions ; 28 parts by weight of nitrogen combine respectively with 16, 32, 48, 64, and 80 parts of oxygen.

Nitric acid is by far the most important of these bodies, and as the whole of the others are prepared from it, nitric acid is conveniently studied first.

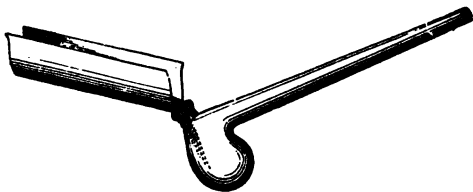
Nitric acid. Formula, HNO_3 . Molecular weight, 62.99. Specific gravity of liquid, 1.52. Melting point, about $-55^\circ C$. Boiling point, 84.5° .

OCCURRENCE.—Nitric acid is produced in small quantities in the atmosphere, from which it is separated by rain, which therefore usually exhibits traces of this acid when subjected to analysis. The salts of nitric acid with soda and potash (sodium and potassium nitrates) are its most common sources. Layers of potassium nitrate are found incrusting the soil in India and of sodium nitrate in parts of Chili and Peru ; the latter of these is the more plentiful.

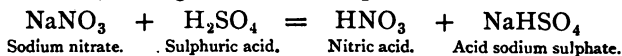
These nitrates are produced by the oxidation of nitrogenous organic matter in the presence of the bases potash or soda. Potassium nitrate is also known as saltpetre or nitre; sodium nitrate is frequently called Chili saltpetre or cubic nitre, from the shape of its crystals.

PREPARATION.—Nitric acid is always prepared by the action of sulphuric acid on a nitrate, usually either that of

FIG. 30.

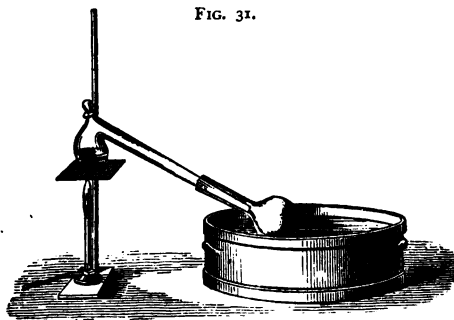


sodium or potassium. The two are mixed in a retort, and on the application of heat, nitric acid, being more volatile, distils over, leaving acid sodium sulphate :—



Experiment 113.—Take a four or six-ounce stoppered retort, get it thoroughly clean, and pour in about an ounce of

FIG. 31.



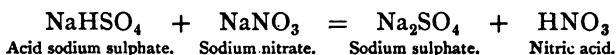
sodium nitrate through the tubulure (i.e. hole for the stopper): this is most easily effected by taking a piece of paper, and doubling it up as shown in Fig. 30; the nitrate is placed on this, and carefully

transferred to the retort, which should be held as in the figure; on no account must any of the nitrate get into the neck.

Preparation and Properties of Nitric Acid. 141

Next clean and drain a small flask or six-inch test-tube and introduce into it the beak of the retort as represented in Fig. 31. Arrange the apparatus in the retort stand with the test-tube or flask well under water in the pneumatic trough ; the further under the better, so that the water does not run into the tube. The retort must be held securely by a ring passing over the neck ; it may be necessary to raise the trough some little distance above the table ; adjustments of this kind are best performed by pieces of blocking ; the trough should be got to its right place *first*, and then filled with water. Next pour in an ounce of concentrated sulphuric acid, replace the stopper, and apply heat carefully with the Bunsen. The nitrate melts, brownish red fumes are seen in the retort, and a pale yellow liquid distils over into the tube or flask. Collect sufficient to about one quarter fill a six-inch test-tube, then remove the light and disconnect the apparatus ; pour the sulphate out of the retort into an evaporating basin while still liquid ; it solidifies, being nearly pure acid sodium sulphate. Reserve the nitric acid for further experiments.

On the application of a more intense heat, the acid sulphate of sodium is capable of acting on another quantity of the nitrate with the formation of the normal sulphate :—

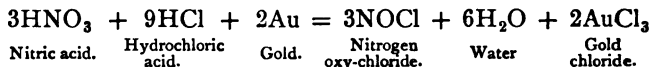


The temperature necessary for this second reaction, however, partly decomposes the nitric acid produced.

PROPERTIES.—Nitric acid, when pure, is a colourless fuming liquid, but usually is of a faint yellow tinge through the presence of some of the lower oxides of nitrogen, produced by its partial decomposition. It is an extremely powerful oxidizing agent, and rapidly destroys animal tissues ; it stains the skin, horn, &c., a bright yellow colour. It attacks most of the metals, including copper, mercury, and silver, with great vigour ; gold and platinum are unaffected by it, or any single acid (except that gold is oxidized by the rare compound, selenic acid).

Experiment 114.—Take a small piece of gold leaf and place it in a test-tube, add some nitric acid, and heat gently: the gold is undissolved. Treat another piece similarly with strong hydrochloric acid, this also is without action; now mix the two together: the gold dissolves rapidly.

This mixture of acids is generally termed *aqua regia* (royal water) from its power of thus dissolving 'the king of metals,' its activity depends on the production of nascent chlorine, which combines with gold forming auric chloride; the reaction may be represented by the following equation, but varies with the different proportions of hydrochloric and nitric acids which may be used—



The action of nitric acid on the metals generally, is more complex than that of hydrochloric or sulphuric acids; the nascent hydrogen, displaced by the metal, attacks the remaining nitric acid, and forms water, liberating one or more of the lower oxides of nitrogen; the particular one evolved, and the proportions of each present in a mixture, depend on the metal used, the degree of concentration of the acid, and other causes.

Experiment 115.—To some of the nitric acid distilled in a previous experiment add one or two pieces of copper clippings; notice that a violent action goes on, ruddy fumes are evolved, and a green solution of copper nitrate formed.

Nitric acid is a monobasic acid, its salts being known as nitrates; they may be prepared either by acting on the metal, as with copper, or by adding the acid to an oxide or a carbonate.

Experiment 116.—Take about half an ounce of strong nitric acid, place it in a beaker, and add solid ammonium carbonate in small quantities until it no longer causes effervescence; the liquid now has an alkaline reaction to litmus paper, add nitric

acid drop by drop until the solution is neutral ; place this away for a week in an evaporating basin ; at the end of that time long needles of ammonium nitrate will have crystallized out ; the salt must be reserved for a future experiment.

The nitrates, like the acid from which they are derived, are powerful oxidizing agents : potassium nitrate is used as a source of oxygen in gunpowder which is a mixture of that compound with sulphur and charcoal.

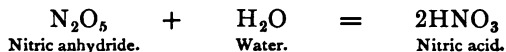
If charcoal be dropped into melting potassium nitrate, it burns with great brilliancy.

Experiment 117.—Melt some potassium nitrate in a test-tube, drop in a fragment of charcoal : it burns with evolution of carbon dioxide. The mouth of the tube should be held away from any person, as sometimes the red-hot piece of charcoal jumps out of the tube.

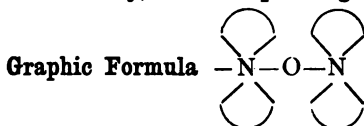
Vigorous combustion of this kind is termed *deflagration*.

All the nitrates are decomposed by heat, oxides of the metals remain, and oxygen and nitrogen oxides are driven off.

NITRIC ANHYDRIDE is an unstable body, and is rarely prepared ; it readily unites with water, and forms nitric acid :—



Nitrogen monoxide. Formula, N_2O . Molecular weight, 43.98. Density, 21.99. Specific gravity, 1.527.



PREPARATION.—This gas may be prepared by the action of zinc on dilute nitric acid, the two being gently heated ; the reaction is a somewhat complex one, and may be represented by the following equation :—



The gas is frequently impure, portions of the nitric acid being reduced to free nitrogen.

Nitrogen monoxide is much more easily obtained by the action of heat on ammonium nitrate, which is decomposed in a manner similar to that in which ammonium nitrite, NH_4NO_2 , is separated into water and nitrogen; the nitrate, however, contains another atom of oxygen (its formula being NH_4NO_3), which is evolved in combination with the nitrogen—

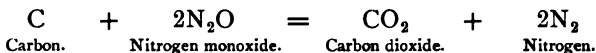


This equation should be compared with that representing the decomposition of ammonium nitrite.

Experiment 118.—Take an eight-ounce flask, fitted with cork and single leading tube; transfer to it the ammonium nitrate prepared according to directions previously given; pour in the saturated solution of the salt as well as the crystals which have formed; get ready a trough of *warm* water for the collection of the gas, fix the flask into the retort stand, place the end of the leading tube in the trough, and apply heat; at first air escapes and bubbles through the water in the trough; this is soon displaced by the steam resulting from the evaporation of the water present with the nitrate; as this enters the colder water it is condensed, and no bubbles arise; in a short time the whole of the water is driven off; at this point the liquid becomes pasty and froths up; watch carefully, and if necessary remove the light; it soon again subsides and then evolves gas quietly; use a flame not too large but just at such a height as to produce a steady and slow current of gas. Collect three jars for experiment; take the leading tube out of the trough, remove the Bunsen, and allow the flask to cool: any ammonium nitrate which then remains readily dissolves if some water is placed in the flask.

PROPERTIES.—Nitrogen monoxide is colourless, has a faint sweetish smell and taste; it is soluble in cold water: 1 volume at 15°C . dissolves 0.77 volumes of the gas. It may be condensed to a liquid by a pressure of thirty atmospheres at 0°C . or at ordinary pressures at a temperature of

—99° C. Nitrogen monoxide supports combustion almost as vigorously as oxygen, oxides are formed, and nitrogen liberated. Carbon thus forms carbon dioxide—

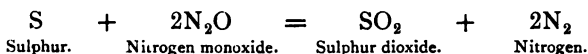


Experiment 119.—Introduce into a jar of the gas a glowing splinter of wood: it bursts into flame as though placed in oxygen.

The two gases, oxygen and nitrogen monoxide, may however, be readily distinguished from each other by the much greater solubility of the latter gas.

The decomposition of nitrogen monoxide into free oxygen and nitrogen is necessary before bodies can burn in this gas: if the heat of the combustion is not sufficient to effect this, burning does not go on. Thus, feebly burning sulphur is extinguished by the gas, but when burning brightly, it continues to do so almost as vividly as in oxygen.

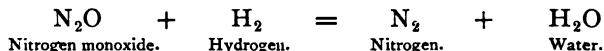
Experiment 120.—Place a piece of sulphur in a deflagrating spoon, let it just take fire in the Bunsen, and plunge it into a jar of the gas: the light is extinguished. Replace the cover of the gas jar, and heat the sulphur in the flame until almost boiling, now again place in the gas: it continues to burn.



Nitrogen monoxide behaves as an anæsthetic when breathed (i.e. a substance which causes insensibility to pain). Some four or five gallons of the gas are sufficient in most cases to produce total insensibility; before this stage it in many persons causes a kind of intoxication, often accompanied by violent fits of laughter; because of this it has received the popular name of 'Laughing Gas.'

The molecule of nitrogen monoxide yields a molecule of nitrogen; therefore, any quantity of the gas, when decomposed, produces its own volume of nitrogen; the composi-

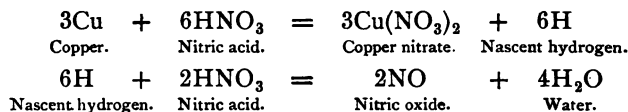
tion may be determined by exploding the gas in the eudiometer with excess of hydrogen—



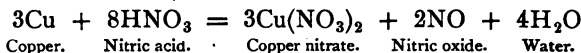
A corresponding volume of nitrogen remains to that of the monoxide taken ; the diminution in volume consists of hydrogen which has combined with the oxygen ; it is necessary, however, to measure the excess of hydrogen which remains, in order to deduce the composition of nitrogen monoxide from this experiment.

Nitrogen dioxide, or nitric oxide. Formula, NO (or N₂O₂). Molecular weight, 29.97. Density, 14.98. Specific gravity, 1.039.

PREPARATION.—This gas is readily obtained by the action of copper on moderately concentrated nitric acid ; the reaction occurs without the application of heat : hydrogen is probably first liberated, and then reduces some of the remaining acid—



Or the two reactions may be stated in the one equation—



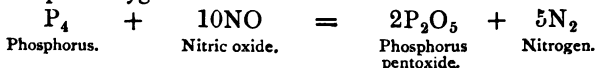
Experiment 121.—Take the flask and delivery tube used for the preparation of hydrogen, No. 2, Fig. 10, and place in it about half an ounce of copper clippings. Dip the cork of the apparatus in melted paraffin, and attach a glass leading-tube to the delivery tube, so that the ends are in contact, by a small piece of india-rubber tubing about two inches long. Nitric acid rapidly corrodes both india-rubber and cork, so that we avoid, as far as possible, exposing either to its influence ; the paraffin protects the cork, and the leading tube is practically of

glass throughout; arrange for the collection of the gas over cold water in the pneumatic trough. Pour on to the copper some of a mixture of strong nitric acid and water in equal volumes (about two ounces): bubbles of gas are evolved and the whole flask rapidly fills with red fumes. These soon become lighter in colour, and as each bubble of gas rises through the water in the trough into the air, it assumes a dark red tint; the air is now expelled from the flask, and the gas jars may be filled; four will be required for experiment. If the action slackens before the whole of them have been filled, add some more of the nitric acid; as the action goes on with great rapidity, as many jars as possible should be filled with water and placed inverted in the trough before the acid is poured on the copper. Remember the order in which the jars are filled. This experiment should, if possible, be performed in a stink closet.

PROPERTIES.—This gas is colourless, but immediately on coming in contact with air, combines with the oxygen and forms higher nitrogen oxides of a ruddy tint; from its possessing these properties, it is difficult to either taste or smell it. The strong odour observed during its preparation is that of these higher oxides.

Nitric oxide has until recently been considered a permanent gas, but was liquefied by Caillietat at -11° C. by a pressure of 104 atmospheres. It is much more stable than nitrogen monoxide, and may be subjected to even a red-heat without decomposition; consequently, a lighted taper does not burn in it.

Phosphorus, when feebly ignited, is also extinguished, but if strongly ignited, burns with almost as much brilliancy as in pure oxygen:—



Experiment 122.—In the third jar of gas prepared, introduce a lighted taper; notice that it goes out. If this is quickly done, a deflagrating spoon containing brightly burning sulphur may be placed in the same jar of gas; this also ceases to burn.

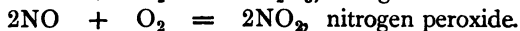
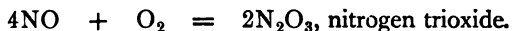
Experiment 123.—Place a piece of phosphorus in the deflagrating spoon, first thoroughly cooling it; get the second jar

of gas ready, and just kindle the phosphorus and *immediately* place it in the gas: it is extinguished. Remove it, and again ignite and let it get to burn brightly; once more plunge it in the jar: it burns with extreme brightness.

A mixture of carbon disulphide vapour and nitric oxide burns with an intense bluish light.

Experiment 124.—Pour half a cubic centimetre of carbon disulphide into a test-tube; replace the bottle. Take the first jar prepared of nitric oxide, remove the cover, quickly pour in the disulphide, and as quickly re-cover the jar; shake it vigorously, in order to thoroughly mix the gas and vapour, holding the plate on firmly. Remove the plate, and apply a light: the mixture burns quietly, with a bright blue flame.

Nitric oxide is not itself combustible. One of its most striking properties is the power it possesses of spontaneously combining with oxygen on the two being brought together; the resultant ruddy gas is a mixture of nitrogen trioxide and peroxide in varying proportions:—



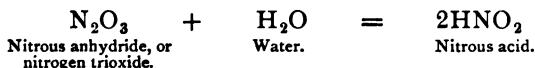
Experiment 125.—Take the fourth jar of gas prepared, and invert it in the pneumatic trough. Having filled a jar with oxygen, pour the gas bubble by bubble up into the nitric oxide; as each bubble enters, a red colour is developed; this again vanishes, and the water rises in the gas jar. If the two gases be pure, the gradual addition of oxygen causes the nitric oxide to disappear entirely.

The reason of this is, that while nitric oxide is but feebly soluble in water (water dissolves about one-twentieth of its volume), the higher oxides produced are very soluble, and are thus absorbed as rapidly as formed. This reaction is a most important one, as the whole process of manufacturing sulphuric acid is dependent on it. A description of its employment for that purpose is given in Chapter XXI.

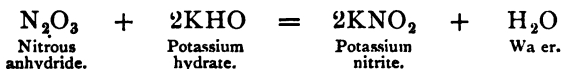
The anomalous composition of nitric oxide has been

already referred to in Chapter XII. From the formula being written N_2O_3 by some chemists, the name *nitrogen dioxide* has been given it, and is still used, although but one atom of oxygen is contained in the molecule. It is a general rule that the more atoms a molecule contains, the more unstable it is. Nitric oxide is more stable than nitrogen monoxide, and this, therefore, is an additional reason for considering its true formula to be NO.

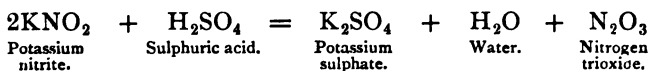
NITROGEN TRIOXIDE is one of the products of oxidation of nitric oxide. It dissolves in a small quantity of water to form nitrous acid. This is, however, so unstable that even the addition of more water causes its decomposition.



If the gas be passed into a solution of caustic potash or ammonia, it is absorbed, and a nitrite is formed.

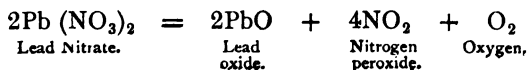


Nitrites are decomposed by stronger acids with evolution of nitrogen trioxide.



NITROGEN PEROXIDE is of but little importance. Like nitric oxide, the formula is anomalous, being NO_2 . At a low temperature, however, the density increases, when N_2O_4 may be considered a true representation of the molecule.

It may be prepared by the action of heat on certain nitrates, as lead nitrate.



Summary.

Five oxides of nitrogen are known, two, at least, of which form acids.

Nitric acid is the most important : is produced by lightning discharges. It is manufactured from nitrates by distillation with sulphuric acid. It is a powerful oxidizing agent, attacks most of the metals, but neither gold nor platinum ; these may be dissolved by *aqua regia*, a mixture of hydrochloric and nitric acids. When metals are acted on by nitric acid, the lower oxides of nitrogen are evolved, and nitrates formed ; they are also produced by acting on metallic oxides or carbonates with the acid. The nitrates also are capable of powerful oxidizing action.

Nitrogen monoxide is usually prepared by heating ammonium nitrate. It is colourless, has faint, sweetish odour and taste, is somewhat soluble in water, non-inflammable, supports combustion, but requires for that purpose an initial heat sufficient to start its decomposition into nitrogen and oxygen. It also acts as an anæsthetic.

Nitric oxide is prepared by the action of copper on nitric acid. It is colourless, but on exposure to air immediately becomes red by combination with oxygen. It is more stable than nitrogen monoxide, and does not support combustion unless the heat of the burning body is sufficiently intense to separate it into oxygen and nitrogen. The red fumes formed by its combination with oxygen are soluble in water. The composition of the gas is anomalous.

Nitrogen trioxide and peroxide are comparatively unimportant.

Laboratory Hints.

Blocking for the adjustment of height of different pieces of apparatus is in constant requisition in the laboratory. Pieces six inches square are of a convenient size ; the following thicknesses should be kept in stock : half-inch, one, two, three, and four inches.

Small pieces of gold-leaf are quite sufficient for the experiments with that substance ; one leaf may be cut into nine pieces. Do not attempt to handle the leaf in a draughty room ; a leaf should be removed from the book, placed on a pad, and

cut with an old knife, the edge of which is quite smooth. When the leaf is cut, it may be taken on the point of the knife and scraped into the test-tube; it may then be washed down by a few drops of water from a wash-bottle.

In adding ammonium carbonate to nitric acid, do not throw it in in the form of a fine powder, as the action then is so violent that it is likely to overflow the beaker. Pieces about the size of peas are the most convenient.

The flask used for the preparation of nitrogen monoxide should not be less than eight ounces, as otherwise some of the melting nitrate may froth up and choke the tube; should any do so, immediately remove the light, as the continued evolution of gas might burst the flask. If the heat is too great, the gas comes over impure; if it is cloudy in the jar, that may be looked on as a sign that the heat must be moderated.

The action of copper on nitric acid sometimes does not start immediately; if so, apply a very gentle heat to the flask until the action commences. It is liable then to proceed with extreme rapidity; a large flask is therefore used. If coming over too fast, pour in a little water; this will render the reaction less violent. The cork and tubing used should be washed at once after use. The directions for the protection of the cork and tubing are important; if a long piece of india-rubber tubing be used, the tubing is not only destroyed, but also gets stopped with the products of corrosion. It is a good plan to have the leading tube bent out of one piece of glass tubing; but if there is a joint, provided the ends of the glass tubes touch one another, it will not matter.

The reason why the order of collection of the gas must be remembered is that that which first comes over is purer. At the last nitrogen monoxide and nitrogen are also present; the jars first filled are therefore used for those experiments in which the purest gas is required.

The phosphorus must be introduced into the gas *very quickly* when lighted, as otherwise it will be burning too brightly to be extinguished. Place the gas-jar close to the Bunsen burner, and loosen the glass plate *before* lighting the phosphorus.

CHAPTER XVIII.

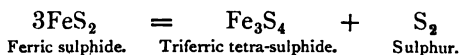
SULPHUR.

Symbol, S. Atomic weight, 31.98. Density, 31.98. Specific gravity of native crystals, 2.07. Molecular weight, 63.96. Molecular volume, \square .

OCCURRENCE.—Sulphur is a widely distributed element. In the neighbourhood of volcanoes it occurs plentifully in the free state. The ores from which many metals are derived are sulphides. Among these may be mentioned those of lead, copper, mercury and zinc. Many of the native metallic sulphides are characterized by a bright metallic lustre. The most common sulphide is that of iron. From this large quantities of sulphur are extracted.

Experiment 126.—Heat a small quantity of powdered native sulphide of iron in a test-tube : yellow drops condense in the upper part of the tube.

The reaction is represented by the following equation:—



In the presence of a limited supply of air the whole of the sulphur is driven off, an oxide of iron remaining. In practice about half of the sulphur is also oxidized into sulphur dioxide, so that the yield of sulphur is not more than 50 per cent. of that present in the ore. The reaction in this case is thus represented, the oxidation of the sulphur being omitted:—



Experiment 127.—Take a piece of combustion tubing six inches long and one quarter-inch diameter ; place a small quantity of the sulphide about half-way up. Hold the tube slanting, and apply heat : an upward current of air is produced, in which the liberated sulphur burns. Smell the gas issuing

from the end : it has the characteristic odour of burning sulphur.

The sulphates are another important class of natural bodies containing sulphur. Of these gypsum or calcium sulphate CaSO_4 , and barium sulphate, BaSO_4 , occur in large quantity.

Many organic bodies contain sulphur as an essential ingredient, especially albumen. Hence, in their putrefaction, sulphur compounds are among the products, and are always present in sewage gases, &c. White of egg is an almost pure form of albumen, and owes its odour when rotten to the presence of a compound of sulphur and hydrogen.

The free sulphur, collected in volcanic districts, is contaminated with earthy impurities. These are removed on the spot, by melting the sulphur from them ; or, in the poorer samples, by the process of distillation. The crude sulphur thus obtained is further purified on its arrival in this country by being a second time distilled. The retorts employed are of iron : the necks lead into large chambers of brickwork. If the heat be applied slowly, the vapour, on entering the chamber, condenses to a solid, and falls as a fine dust to its floor. This constitutes 'flowers of sulphur.' At a higher temperature the walls are heated, the sulphur condenses to the liquid form on them, and runs to the bottom as a melted mass. This is drawn off into cylindrical wooden moulds, and allowed to solidify. In this manner is produced the roll 'brimstone' of commerce.

PROPERTIES.—Sulphur is a lemon-yellow solid. It is insoluble in water, and therefore possesses no taste, but has a faint odour. The rolls of sulphur are extremely brittle, and as it is also a bad conductor of heat, the warmth of the hand is sufficient to often cause a roll to fall in pieces when held. It melts at a temperature of 113°C. to a limpid yellow liquid, which, if allowed to cool slowly, deposits long prismatic needle-like crystals. These are at first perfectly transparent, but after a time become opaque, through each

breaking up into a number of minute rhombic octahedral crystals. The external form is still retained, but little coherence remains.

Experiment 128.—Take a clay crucible about three inches high, or, preferably, an iron ladle; fill it with sulphur, and heat very gently with a small flame, taking care that the sulphur and the flame do not come in contact. As soon as the whole of the sulphur is melted, remove the Bunsen: as it cools, a crust forms over the surface, crystals being seen to shoot out from the side. Immediately that this crust is formed, bore two holes through with a red-hot iron wire close to the edge and opposite each other; pour the sulphur (which still remains melted) out, and then cut round the upper crust with a knife and remove it: the interior is one mass of long transparent needles (prisms), belonging to the oblique system. Set the mass aside for a week, and then observe that the crystals have lost their transparency.

If sulphur be dissolved in carbon disulphide, and the liquid then allowed to evaporate, the sulphur is obtained in octahedral crystals of the rhombic system. These are permanent in air, and the form is that in which native sulphur crystals occur.

These are, then, two distinct forms in which sulphur crystallizes; the one from fusion, the other from solution. The latter are permanent, the former unstable, gradually changing into the latter.

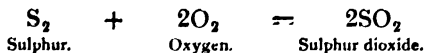
In addition to these two varieties, there is another known as plastic sulphur, whose properties widely differ from those of either. If, instead of allowing the limpid yellow liquid, produced as a result of melting sulphur, to cool, the application of heat be continued, a remarkable series of changes ensues. The colour gradually darkens as the temperature rises; at the same time the liquid becomes thicker, until, at a temperature of 180° C., the mass is almost black, and so viscid that the vessel may be momentarily held inverted without the sulphur running out. With a further increase of temperature, the sulphur again becomes liquid, but re-

mains of a much thicker consistency than it possessed on first melting. If while in this state it be poured into water, a soft, india-rubber-like mass is produced, of a yellowish-brown tint, which may be drawn out into long threads. The difference between these and the common brittle form of sulphur is very striking. In a few hours it loses its tenacity, becoming again opaque and brittle. At a temperature of 446° sulphur boils.

In addition to the three forms of sulphur described, there are some other varieties, which, however, are not of great importance.

Experiment 129.—Place some sulphur in a test-tube, heat very gently, and notice the successive changes, from a thin liquid of light colour to the almost black, treacly mass. When in this condition invert the tube: the sulphur does not run out, or only very slowly. Continue the application of heat until the sulphur boils; observe the dark yellow vapour, which condenses to solid yellow particles in the upper part of the tube. Pour the liquid into a trough of cold water; notice the plastic condition of the sulphur; reserve some for a week, it will have become brittle.

Sulphur is highly inflammable, burning in air with a pale blue flame, and emitting a suffocating odour, the reaction being represented by—



A higher oxide of sulphur is also known, the formation of which will be subsequently described.

Sulphur also combines readily with other elements. Iron, copper, and others, burn brightly when heated with it. Silver and sulphur combine at ordinary temperatures, giving the metal a black coating of silver sulphide.

Two compounds of sulphur with hydrogen are known— SH_2 and S_2H_2 —which are analogous in composition to the oxides of hydrogen, OH_2 and O_2H_2 . The first of these is

the only one of practical importance. The sulphides of the metals have usually corresponding formulæ to the oxides. Thus the sulphide of copper is CuS ; the oxide, CuO . Sulphur in these compounds behaves as a dyad; but in sulphuric acid and the sulphates its atomicity is VI.

Summary.

Sulphur is found in volcanic districts, also in sulphides and sulphates, and several organic bodies; is purified by distillation; is a lemon-yellow brittle solid; occurs in two crystalline forms, one of which is unstable; may be also obtained in the plastic form by the application of heat. It is highly inflammable, and combines with most of the metals, and also with many of the non-metals. Its absolute atomicity is VI.

Laboratory Hints.

For the first experiment in this chapter the native sulphide should be used: that employed in the manufacture of sulphuric acid is most suitable. To succeed in obtaining sulphur crystals by solidification of the melted body, bore the holes through the crust *immediately* it forms, and drain the melted sulphur away *completely*.

In pouring sulphur from a test-tube there is danger of the tube cracking, unless the upper part is thoroughly heated. The safest plan is, before pouring, to boil the sulphur until the whole tube is full of uncondensed vapour; by this means the whole is uniformly heated, and the danger of cracking is but little; care should, however, be taken that the tube is so held that in the event of its breaking none of the sulphur should fall on the hands. The liquid will probably take fire as it leaves the test tube: this, however, is of no importance. Should any fall on the bench, at once throw a little water on it.

CHAPTER XIX.

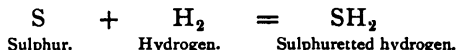
SULPHURETTED HYDROGEN.

Formula, SH_2 . Molecular weight, 33.93. Density, 16.99. Specific gravity, 1.1912.

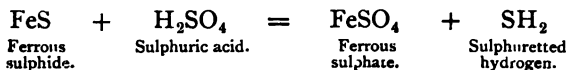


THIS compound, which is also sometimes known by the name of hydrosulphuric acid, is found free in volcanic districts, and also in the waters of certain mineral springs, as those at Harrogate.

PREPARATION.—It is formed when hydrogen is passed into sulphur vapour, but only in small quantities.



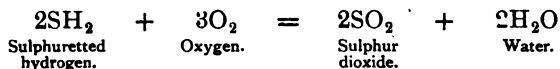
It is commonly prepared for use in the laboratory by the action of dilute sulphuric acid on a sulphide, that of iron being usually chosen. The reaction goes on readily, without the application of heat, the iron displacing the hydrogen, and the sulphur and hydrogen uniting.



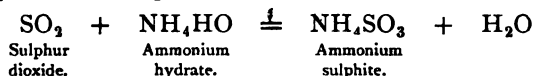
Experiment 130.—Fit up the apparatus used for the preparation of hydrogen, attach a small flask as a wash-bottle (Fig. 32), and place in it a little water; place in the flask some fragments of iron sulphide; add three or four ounces of water, and then a *small* quantity of sulphuric acid: the gas is rapidly evolved. Fill three jars with it over warm water.

Experiment 131.—In the next place, attach a jet to the generating apparatus, and light the gas: it burns with a feeble blue flame, producing water and sulphur dioxide. Hold just above the flame a rod which has been dipped in a strong solution of ammonia (ammonium hydrate): dense white fumes ascend.

The combustion of sulphuretted hydrogen is represented by the equation—



On holding above the flame the rod dipped in ammonia, the sulphur dioxide forms a solid compound, named ammonium sulphite. The fumes of this body are evidence of the presence of sulphur dioxide.



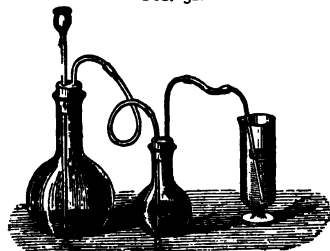
Sulphuretted hydrogen produces no fumes with ammonia. More conclusive evidence of the presence of sulphur dioxide as one of the products of combustion is afforded by holding the nose above the flame, when its characteristic odour is observed. The following experiment also illustrates a test frequently employed for the detection of sulphur dioxide:—

Experiment 132.—Hold over the flame a piece of filter paper which has been dipped in a mixture of potassium chromate and dilute hydrochloric acid: the yellow colour is changed to green by the reducing action of the sulphur dioxide.

Prove also that water is produced, when sulphuretted hydrogen burns, by holding a beaker of cold water in the flame: moisture condenses on the cold surface.

Sulphuretted hydrogen is soluble in cold water, one volume at 15° C. dissolving 3·23 volumes of the gas.

FIG. 32.



the ferrous sulphide in flask A. Continue the passage of the gas

Experiment 133.—At the conclusion of the experiment with flame pass the gas into a little distilled water in a test-glass or beaker—the arrangement of the apparatus is shown in Fig. 32. If necessary, add a little more sulphuric acid to

for about ten minutes, and then notice that the water has the odour of the gas.

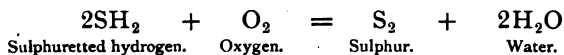
While the above experiment is proceeding, examine the three jars filled with the gas in the following manner:—

Experiment 134.—Remove the cover from one jar, and introduce a lighted taper : the gas burns, but the light is extinguished : a yellow deposit of sulphur is formed on the sides of the jar.

Experiment 135.—Add some litmus solution to the second jar of gas, and shake up : the colour of the litmus is changed to a port wine tint, showing that the gas has feebly acid properties.

Experiment 136.—Prepare a jar of chlorine, invert it, with the plate on the mouth, over the third jar of sulphuretted hydrogen ; pull out the two plates and the jars open into one another : sulphur is deposited. Remove the upper jar, and notice the characteristic fumes of hydrochloric acid.

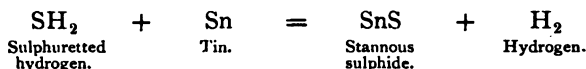
PROPERTIES.—The preceding experiments illustrate several of the properties of this gas. It is colourless, and has an odour of rotten eggs. Its solution in water has a corresponding taste. It is inflammable and a non-supporter of combustion. With excess of oxygen, sulphur dioxide and water are produced, according to the equation before given. When the supply of air is limited, as when the gas burns in a jar, the sulphur is in great part deposited, the hydrogen only being burned.



The gas is condensed to a liquid by a pressure of seventeen atmospheres at ordinary temperatures.

The molecule of the gas being represented by the formula SH_2 , it is evident that it contains its own volume of hydrogen. Its composition may be proved by heating metallic tin in it. When cold, the gas is found to have regained its original volume, and to consist of hydrogen. A piece of paper dipped in a solution of lead acetate is not

changed in colour by the residual gas, although it is immediately blackened by sulphuretted hydrogen. The sulphur and tin have combined to form stannous sulphide.

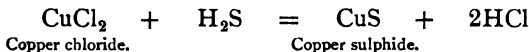


The experiment may be performed in the following manner :—

Experiment 137.—First close the end of a piece of combustion tubing, eight or ten inches in length, blowing it out into a small bulb; bend it over, about two inches from the end, to an acute angle. Place a few fragments of granulated tin in the closed end; fill with sulphuretted hydrogen by displacement, and then invert in a small trough of mercury. The mercury should stand in the tube some distance from the bottom; some of the gas must therefore be allowed to escape by holding the tube over at an angle, its mouth being kept the whole of the time under the surface of the mercury. Clamp the tube with a holder, and apply heat very carefully: the sulphur and tin combine. Allow to cool, and observe the volume. Before heating, an india-rubber ring should be slipped over the tube to mark the level of the gas.

The action of sulphuretted hydrogen on litmus shows that the gas possesses acid properties. These are, however, so feeble that in the case of soluble sulphides, carbon dioxide is able to displace the sulphuretted hydrogen. The sulphides of all the metals are insoluble in water, with the exception of those of calcium, barium, strontium, magnesium, sodium and potassium, and a few of the very rare metals. The insolubility of the other metallic sulphides affords to the analyst a very valuable means of separating those metals from the group above mentioned. Whenever two compounds are brought together which respectively contain elements that by their union are capable of forming an insoluble compound, that compound will usually be produced; so that, although sulphuretted hydrogen is a weak acid, it is thus able to displace stronger ones from many metals. A

current of sulphuretted hydrogen passed through a solution of copper chloride precipitates copper sulphide thus—

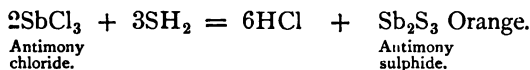
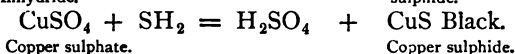
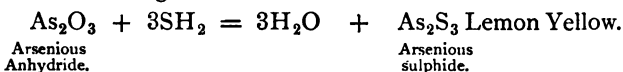


And this, although hydrochloric acid is so much more powerful in its properties.

These sulphides have, in many cases, characteristic colours, by which they are immediately recognised. They possess the further advantage of being divided into two groups, one of which is soluble in dilute hydrochloric acid, the other not so.

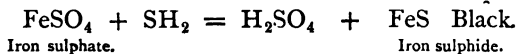
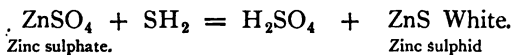
Experiment 138.—Prepare a solution in separate test-tubes of each of the following substances :—Arsenious anhydride, copper sulphate, lead acetate, tartar emetic or antimony chloride, zinc sulphate, and ferrous sulphate. Add a few drops of hydrochloric acid to each, and pass sulphuretted hydrogen through each solution from the generating apparatus, washing the leading tube between each solution.

The following results are observed:—



ZnSO_4 Zinc Sulphate } In acid solution SH_2 produces no
 FeSO_4 Iron Sulphate } precipitate.

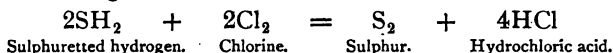
Through fresh portions of zinc and iron sulphates, *without* the addition of hydrochloric acid, pass sulphuretted hydrogen:—



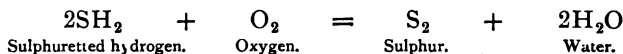
To these two now add a few drops of hydrochloric acid : the precipitates are immediately redissolved.

The sulphides are shown by these experiments to be well-defined salts, and a series of bodies of great importance.

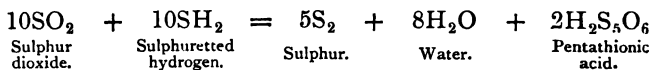
Although sulphur is thus able to displace the metals from their compounds with chlorine, owing to the operation of the law previously mentioned, yet chlorine readily decomposes sulphuretted hydrogen, as shown by experiment, the action being—



The great affinity of hydrogen and chlorine for each other causes the decomposition of the sulphuretted hydrogen. Free oxygen has no action on the dry gas, but in the presence of water a slow oxidation takes place. Hence an aqueous solution of sulphuretted hydrogen becomes turbid on exposure to the atmosphere, through the separation of sulphur and the formation of water.



A curious and interesting reaction takes place between sulphuretted hydrogen and sulphur dioxide when moist : on bringing together the mouths of two jars containing these gases, they decompose each other with the separation of sulphur and formation of water. Apparently, the decomposition is in part determined by the affinity of the sulphur atoms for each other, in the same way as the affinity of oxygen atoms causes the mutual decomposition of hydroxyl and silver oxide. In the above reaction an acid of sulphur known as pentathionic acid is also formed—



This reaction is of interest as being that by which probably much of native sulphur has been deposited, both of these gases being emitted from volcanoes.

Properties of Sulphuretted Hydrogen. 163

Under sulphur dioxide directions are given for the performance of this experiment.

Summary.

Sulphuretted hydrogen occurs free in the gases evolved from volcanoes. May be prepared by passing hydrogen into sulphur vapour; also by the action of sulphuric acid on sulphides. It burns in excess of air to sulphur dioxide and water; with less air sulphur is deposited. The sulphur dioxide produced by its burning may be recognised by its action with ammonia, and also on a mixture of potassium chromate and hydrochloric acid. Sulphuretted hydrogen is soluble in water; is colourless, and has a disgusting odour of rotten eggs; is a non-supporter of combustion. By the action of chlorine it is decomposed. A given volume of the gas contains its own volume of hydrogen; its composition is determined by heating it with metallic tin. It possesses feeble acid properties; certain sulphides possess characteristic colours by which they may be recognised.

Sulphuretted hydrogen is also decomposed by sulphur dioxide.

Laboratory Hints.

After the preparation of sulphuretted hydrogen wash out the apparatus before it is put away; otherwise a mass of crystal of iron sulphate may form. Any remaining iron sulphide should be washed, and returned, when dry, to the jar. There is sometimes some difficulty, when sulphide is taken which has been before used, in getting the action to commence; there should always be a little new sulphide added as well. The difficulty sometimes arises through the acid being too strong.

In experiment 136, take care that the tin is not allowed to drop into the mercury. The application of heat should be continued for some time.

CHAPTER XX.

OXIDES OF SULPHUR.

THREE oxides of sulphur are known :—

Sulphur sesquioxide, S_2O_3

Sulphur dioxide or sulphurous anhydride, SO_2

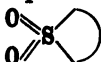
Sulphur trioxide or sulphuric anhydride, SO_3

The latter two of these only will be considered in this work.

SULPHUR DIOXIDE AND SULPHUROUS ACID.

Sulphur dioxide. Formula, SO_2 . Molecular weight, 63.9. Density, 31.95. Specific gravity, 2.247.

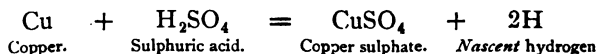
Graphic Formula,



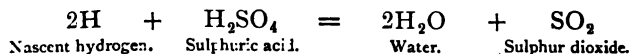
This compound is a gas at ordinary temperatures and is emitted in vast quantities from volcanoes. The student is already familiar with its preparation by the combustion of sulphur in oxygen.

PREPARATION.—When required for laboratory use it is prepared by the action of some deoxidizing agent on sulphuric acid.

It has been already shown that zinc energetically displaces the hydrogen from sulphuric acid; but certain other metals, as copper, silver, and mercury, are without action, except on the application of heat, when chemical action ensues, which is probably represented by the following equation :—

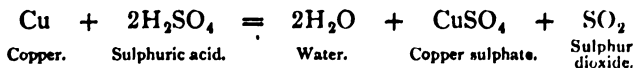


At the high temperature the nascent hydrogen attacks a second molecule of sulphuric acid, thus :—

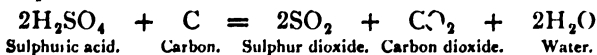


Preparation and Properties of Sulphur Dioxide. 165

These successive steps in the reaction may be grouped together in one equation :—



Sulphur dioxide may also be prepared from sulphuric acid by the action of charcoal ; carbon dioxide, however, is also produced :—



The gas being soluble in water must be collected by displacement or over mercury. For the purpose of testing the properties of the gas, prepare three jars in the following manner :—

Experiment 139.—Fit up the generating apparatus shown in Fig. 33, put in about half an ounce of copper turnings or strips, set the flask on a tripod or retort stand, pour in three ounces of strong commercial sulphuric acid, and apply heat. After a time, as the temperature increases, the liquid in the flask effervesces, and sulphur dioxide is evolved ; collect by downward displacement. To determine when the jar is full, hold a match near its mouth : the gas extinguishes it. As soon as the action commences the flame may be lowered. The jars and plates used must be quite dry.

FIG. 33.

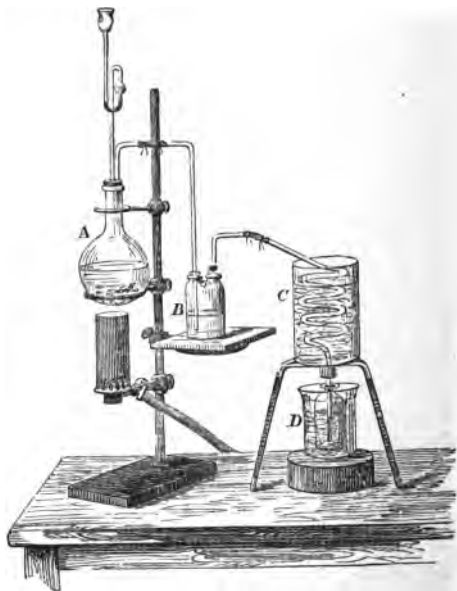


PROPERTIES.—At a temperature of -8° C. sulphur dioxide condenses to a colourless liquid, which freezes at

-76°C. ; at 15°C. the gas condenses with a pressure of $2\frac{1}{2}$ atmospheres.

Experiment 140.—Dry the gas evolved from the generating apparatus by passing it through concentrated sulphuric acid in a small wash-bottle; next pass it through a spiral glass, or pewter worm, enclosed in a vessel containing a mixture of ice and salt. Let the end of the spiral dip into a test-tube, which

FIG.



is also placed in some of the ice and salt mixture ; as the gas passes through the worm it is condensed, and collects in the test-tube. When a little of the liquid has accumulated, pour it on the bulb of an alcohol thermometer, around which cotton-wool has been wrapped : notice the great cold produced by the rapid evaporation. The gas may be retained in the liquid form by hermetically sealing the tube containing it ; the upper end may be softened and drawn off by the blow-pipe while the tube remains in the freezing mixture.

Fig. 34 represents a form of the apparatus : A is the generating flask, B the wash-bottle, C the condensing worm, and D the small bottle, or test-tube, in which the liquefied gas is collected.

Experiment 141.—In one of the jars of gas place a burning taper : it is immediately extinguished, and the gas does not take fire. In the same bottle pour a little litmus solution, and shake up : the colour changes to red, and in a little while disappears.

Experiment 142.—Open the second jar under water in the trough : the water rushes up, and fills the jar. Pass some of the gas, after washing in a very small wash-bottle containing a layer of about half an inch of water, into a little distilled water in a beaker, in the same way as sulphuretted hydrogen was obtained in solution : notice that the gas is almost entirely dissolved, and that the liquid acquires the taste and smell of the gas.

Experiment 143.—Hold over the jet from which the gas is issuing a piece of paper dipped in a mixture of a solution of potassium chromate and hydrochloric acid : the colour is changed from yellow to green. This is a convenient test for the presence of sulphur dioxide.

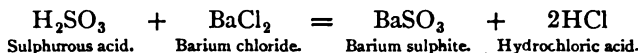
Experiment 144.—Prepare a jar of sulphuretted hydrogen, and place on it the remaining jar of sulphur dioxide ; remove the plates : observe that sulphur is deposited. The reaction was described with an equation in the last chapter.

From experiments the student has seen that sulphur dioxide is a colourless gas with a strong pungent odour ; when diluted with air coughing and sneezing are produced by it ; in a concentrated form it causes suffocation. Water at a temperature of 15°C . dissolves 47 volumes of this gas : the solution thus produced contains a true acid, sulphurous acid, H_2SO_3 , which separates out in cubical crystals at 0°C . ; this is decomposed at a higher temperature, sulphur dioxide escapes, and water remains ; the whole of the gas may be expelled from water by boiling.



Experiment 145.—Add to some of the sulphurous acid pre-

viously made some barium chloride solution : a white precipitate of barium sulphite is formed :—



To this add a little pure dilute hydrochloric acid : the precipitate immediately dissolves.

Place some of the solution away in a beaker or evaporating basin for a week, then add to it some barium chloride and hydrochloric acid : the white precipitate which first formed does not probably entirely dissolve.

Like other gases which readily condense, sulphur dioxide does not implicitly follow Boyle's law (p. 25) ; the pressure being doubled, the volume contracts to less than one-half.

The gas is neither inflammable nor a supporter of combustion.

The action of sulphur dioxide on litmus shows its acidity when in solution ; the further action by means of which it discharges the colour, indicates that it possesses bleaching properties. As a bleaching agent it differs remarkably from chlorine ; it will be remembered that the latter decomposes water, seizing the hydrogen, and that the nascent oxygen destroys the colouring matter by change into bodies containing a larger proportion of that element.

Colouring matters which have been acted on by chlorine are entirely destroyed, and cannot be reproduced ; colours removed by sulphur dioxide are again restored either by its displacement by a stronger acid, as dilute sulphuric, or its neutralization by combination with an alkali. Miller considers the acid to act by forming colourless compounds with the colouring matters. The action is also explained by stating that the colouring matters are reduced, the sulphurous acid being oxidized into sulphuric ; it is difficult, however, with this assumption, to explain how the addition of either sulphuric acid or an alkali should again restore the colour, as neither of these bodies are oxidizing agents. Sulphur dioxide is used for the bleaching of articles, such as

silk, straw, and wool, which would be injured by the action of chlorine.

Experiment 146.—Suspend in the upper part of a deflagrating jar a bunch of red roses, or other coloured flowers ; stand the jar on a dish, over a small spoon or iron plate containing some burning sulphur : the sulphur dioxide, as formed, discharges the colour. Next dip the flowers in water acidulated with sulphuric acid : the colour is restored.

In the absence of freshly gathered flowers, an infusion of red roses may be employed, and some of the sulphurous acid made in a former experiment added to it.

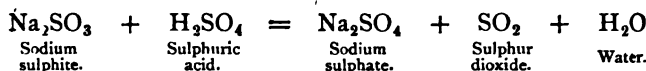
Sulphur dioxide is used for the purpose of removing traces of chlorine from goods bleached by that agent, sulphuric and hydrochloric acids are formed by their mutual action, and may be afterwards removed by copious washing ; more usually, however, the sodium salt of sulphurous acid is employed ; this possesses the advantage that the alkaline base combines with the resulting acids and forms non-corrosive salts.

From its possessing this property, sodium sulphite is known commercially under the name of antichlor. Its action is represented in the following equation, where it is assumed that excess of the sulphite is used :—



As the molecule of sulphur dioxide contains two atoms of oxygen, it yields on decomposition its own volume of that gas ; or on burning sulphur in oxygen over mercury, the volume of the gas remains unaltered ; from the atomic weight of sulphur being (very nearly) double that of oxygen, the molecular weight of sulphur dioxide is also double that of oxygen.

Sulphurous acid is dibasic and forms two series of salts called sulphites ; these are all decomposed by the action of a stronger acid, as sulphuric :—

*Summary.*

Sulphur dioxide is emitted from volcanoes, is prepared by burning sulphur in air or oxygen, and by action of copper, carbon, or sulphur, on sulphuric acid. The gas has a pungent odour, is colourless, possesses a characteristic taste, and may be condensed to a liquid by either cold or pressure. It is very soluble in water; the solution is acid to litmus, and contains a true acid, forming a series of salts known as sulphites.

Sulphurous acid acts as a bleaching agent; the colour, however, is restored by either the action of very dilute acid or an alkali.

Laboratory Hints.

In inserting copper strips in a flask take care that they do not drop through the bottom; the best plan is to hold the flask in a horizontal position and slide them in.

In heating sulphuric acid, take every precaution to prevent the cracking of the flask; for instance, do not let the flame play direct on the glass. Never hold the hands where there is any danger, in event of a breakage, of the hot acid running on them. Should such a misfortune, by any accident, happen, *immediately* place the burned part under a copious stream of water from the tap. If sulphuric acid is spilled over the woodwork of the bench, strew over it some whiting, and when the action is over let the whole be cleaned up with sawdust.

To make a freezing mixture, pound together in a mortar two parts of ice and one of salt; scrape this into the vessel containing the condensing worm for the condensation of sulphur dioxide. If such a condenser has to be fitted up, a deflagrating jar turned bottom upwards answers very well for the outer vessel; the mouth should be fitted with a cork, through which the end of the condensing spiral is passed. A worm made of pewter possesses the advantage of being unbreakable.

Should it be desired to preserve a sample in the liquid state, a tube of stouter glass than a test-tube must be employed; it should be drawn out at the neck before being filled, so that the final sealing may be done more quickly. Take care, however, not to draw out the neck so narrow as to prevent the tube from the end of the condenser passing in.

CHAPTER XXI.

SULPHUR TRIOXIDE AND SULPHURIC ACID.

Sulphur Trioxide. Formula, SO_3 . Molecular weight 79.86. Density, 39.93.

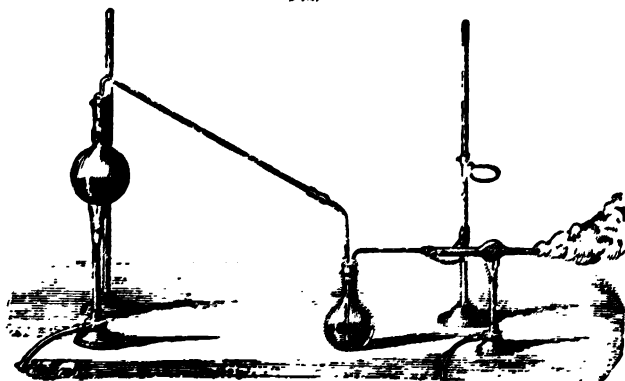
Graphic Formula, $\text{O}=\text{S}\begin{smallmatrix} \diagup \text{O} \\ \diagdown \text{O} \end{smallmatrix}$

SULPHUR does not readily combine with more than two atoms of oxygen ; but by passing a mixture of sulphur dioxide and oxygen over ignited spongy platinum, sulphur trioxide is produced.



Experiment 147.—Fit up a four-ounce flask as a wash-bottle, and one third fill it with a saturated solution of sulphurous acid

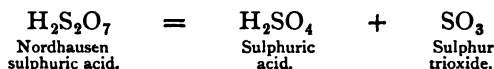
FIG.



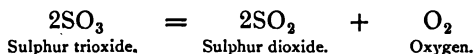
in water. Attach to the long tube in the flask an oxygen generating apparatus (either a small flask or test-tube). Blow a bulb in the centre of a piece of combustion tubing about nine inches long ; draw off one end to the size of a piece of quill tubing, and fit a cork and leading tube to the other end. Take some asbestos and soak in a solution of potassium chloride ;

dry it, and ignite in a small crucible over the Bunsen; the chlorine is driven off, and a finely divided coating of platinum remains on the asbestos. Introduce this into the bulb of the tube, and connect up the whole by india-rubber tubing as shown in Fig. 35. Heat the oxygen tube; the gas, in bubbling through the sulphurous acid, disengages some sulphur dioxide, a mixture of the two emerges and passes through the bulb tube. Now heat the bulb containing the platinized asbestos, white fumes of sulphur trioxide issue from the tube; convey these by means of a piece of glass tubing, attached with india-rubber, into some distilled water in a small beaker. Add to the water some pure hydrochloric acid and barium chloride: an insoluble precipitate is formed.

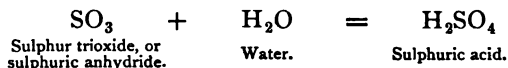
Sulphur trioxide is also produced by the action of heat on Nordhausen sulphuric acid thus—



PROPERTIES.—Sulphur trioxide, as obtained by either of the methods above given, is a white silky-looking mass, which, when purified by repeated distillations in hermetically sealed tubes, is changed into a colourless liquid. It is devoid of all acid properties, and may be rolled between the *dry* fingers without injury. By passage through a red-hot tube, it is separated into oxygen and sulphur dioxide.



Sulphur trioxide is very deliquescent, and when dropped into water, dissolves with a hissing noise and evolution of great heat, forming sulphuric acid.

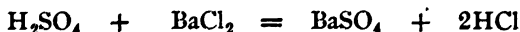


When the two are once united, their separation cannot be effected by heat alone; for a temperature sufficiently high to dissociate them, also decomposes sulphur trioxide into sulphur dioxide and oxygen.

Sulphuric Acid. Formula, H_2SO_4 . Molecular weight, 97.92. Specific gravity of liquid, 1.846. Melting point, 10.5°C . Boiling point, 338° .

There is no other compound, with the exception of water, which is of such importance to the chemist as sulphuric acid. The frequency of its application to various purposes in the preceding chapters will have given the student some idea of its usefulness, and have rendered him familiar with its appearance, many of its properties, and its composition. It holds an equally important position in the chemical manufactures, as in the laboratory. Its preparation is the starting-point in the manufacture of hydrochloric acid, sodium carbonate, nitric acid, and many other bodies of value in the arts.

PREPARATION.—Sulphurous acid, when exposed to the atmosphere, is gradually oxidized to sulphuric acid, as was proved by an experiment described in the preceding chapter, where directions are given for some sulphurous acid to be left in an open evaporating basin for a week. A solution of barium chloride is employed as a test for sulphuric acid, with which it forms a white precipitate, insoluble in acids.



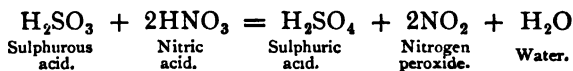
Sulphuric acid. Barium chloride. Barium sulphate. Hydrochloric acid.

The same precipitate is formed when barium chloride is added to a solution of a soluble sulphate. Barium chloride also produces a precipitate with sulphurous acid, which is, however, soluble in hydrochloric acid. In this way the two acids are distinguished from each other, and sulphuric acid detected in the other's presence.

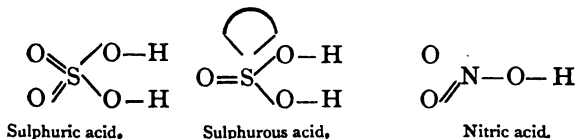
The change of sulphurous into sulphuric acid is produced more rapidly by the aid of oxidizing agents.

Experiment 148.—To a little sulphurous acid, free from sulphuric acid, add a few drops of pure concentrated nitric acid; heat gently in a test tube; add some hydrochloric acid and barium chloride: a white precipitate of barium sulphate is formed.

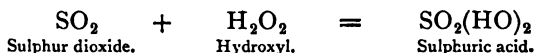
The action of the nitric acid is thus represented :—



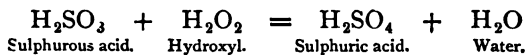
Sulphurous acid may be also oxidized by the action of hydroxyl. This reaction is of some theoretical importance, as many chemists view the acids as a class of bodies in which the hydrogen exists as semi-molecules of hydroxyl. Frankland, to whom we are indebted for a systematic nomenclature which indicates the constitution of bodies, writes the formula of sulphuric acid, SO_2Ho_2 . Ho is here used to represent the semi-molecule of hydroxyl, the small 2 qualifying both the hydrogen and oxygen. The same formula is conveniently written $\text{SO}_2(\text{HO})_2$. The constitution of oxy-acids is represented according to this theory by the following graphic formulæ:—



The peculiar interest of the oxidation of sulphur dioxide into sulphuric acid by hydroxyl depends on the fact that it may be regarded as an instance of direct union between the two compounds, thus—



The reaction may also be expressed by an equation in which sulphurous acid is oxidized by the second atom of oxygen in hydroxyl.



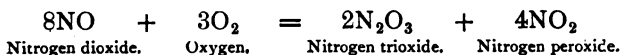
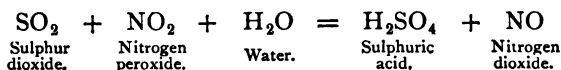
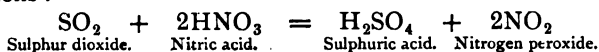
Sulphur itself, when moistened, is in part gradually

oxidized into sulphuric acid; by prolonged boiling with nitric acid, the whole becomes oxidized.



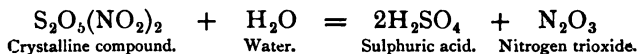
Nitric acid has a similar action on some native sulphides.

Sulphuric acid is always manufactured on the large scale by the oxidation of sulphur dioxide in the presence of water. The reactions involved are of great beauty and interest. The vapour of nitric acid is passed into a chamber with sulphur dioxide, air, and steam. As shown in a previous experiment, the nitric acid is deoxidized into nitrogen peroxide, with the formation of sulphuric acid. A reaction now ensues between the nitrogen peroxide and some more sulphur dioxide, more sulphuric acid is produced, and the nitrogen peroxide is reduced to nitrogen dioxide. The student will remember that in the presence of air this colourless gas is immediately changed into the ruddy fumes of the trioxide and peroxide. Thus, higher oxides of nitrogen are again formed, and are capable of oxidizing more sulphur dioxide. Sulphur dioxide does not readily combine with oxygen, but is immediately oxidized by nitrogen peroxide. The dioxide unites directly with oxygen, and so acts as a carrier of oxygen from the air to the sulphur dioxide. A small amount of nitric acid is thus capable of producing an indefinite quantity of sulphuric acid. The whole series of changes are shown in the following equations:—



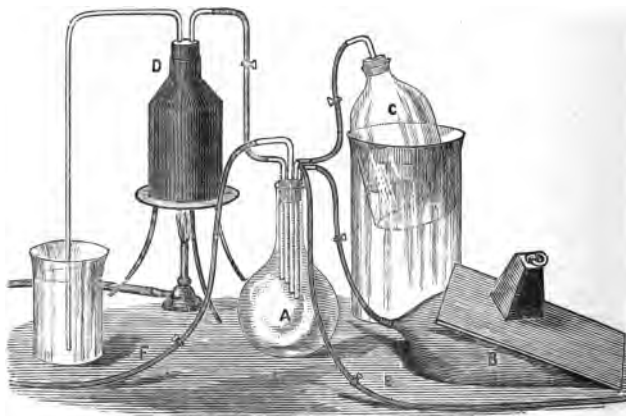
The proportions of higher oxides are not constant, but depend on the quantity of oxygen present.

The above equations represent, in the simplest form, the action which takes place. In the absence of water a peculiar crystalline compound is produced, which may be represented by the formula $\text{S}_2\text{O}_5(\text{NO}_2)_2$. This is immediately decomposed by water, with the formation of sulphuric acid and liberation of nitrogen trioxide:—



Experiment 149.—In order to study the reactions above explained, fit up the following apparatus: To a dry 32-ounce

FIG. 36.



flask fit a cork, through which bore five holes, and pass through each a piece of glass tubing bent at right angles, four of which reach to about the middle of the flask: to these attach respectively, by india-rubber tubing, an apparatus for the generation of nitrogen dioxide, another evolving sulphur dioxide, a bag containing air, with a weight on the top, and a flask for the production of steam. Through the fifth hole a tube is passed, which just enters the flask. This is provided for the escape of the

Experimental Preparation of Sulphuric Acid. 177

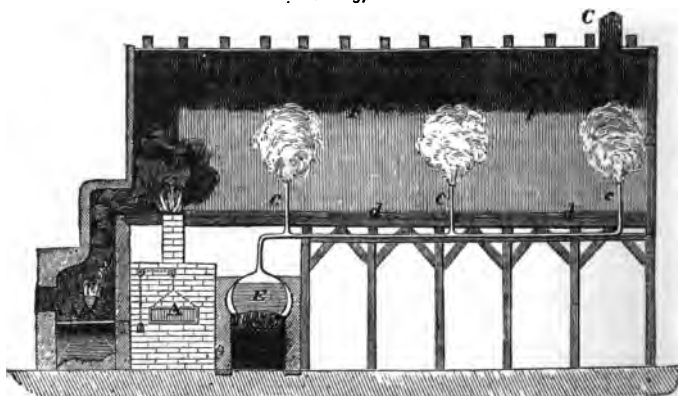
waste gases ; it should be larger than the others, and have a tube leading from it into a flue or sink cupboard. Instead of having generating flasks for the sulphur and nitrogen oxides, it is a far more convenient plan to prepare these gases previously, and store them in little gas holders or bladders ; a dry bullock's bladder, through the neck of which a glass tube is passed, answers very well for the sulphur dioxide ; the nitric oxide may be kept in a little gas holder over water. A screw tap should be placed on the india-rubber tubing connecting each of these to the flask. If this form of the apparatus is used, the student's attention is not required in watching and regulating the evolution of the gases, but instead, he can observe minutely the reactions taking place in the flask. The flask or other vessel in which the water is being boiled should have another outlet provided for the steam ; this may conveniently consist of a tube leading to the bottom of a beaker in which there are about four or five inches of water. When the connection between the water flask and the other is closed, the steam forces its way through the water in the beaker ; when this pipe is opened, the steam takes the channel offering least resistance, viz. into the flask. Fig. 36 shows the whole arrangement. A is the flask in which the reaction goes on ; B is a bladder containing sulphur dioxide under a weight ; C a gas holder containing nitric oxide ; D is the water flask with escape tube leading into beaker ; E conveys air from gas bag not shown in figure ; F is the exit tube for the waste gases. A description of the gas holder is given in the laboratory hints for this chapter. The flask having been thoroughly dried, and every thing being in readiness, allow a slow current of air, sulphur dioxide, and nitric oxide to pass into the flask : the ruddy fumes at first formed disappear, and a crystalline deposit is observed on the sides of the flask. Now shut off the whole of these, and admit steam : the crystalline compound disappears, nitrous fumes are evolved, and sulphuric acid condenses and collects at the bottom of the flask. Then re-admit sulphur dioxide, and in the presence of steam the nitrous fumes disappear ; add air, they are again formed ; keep up a slow current of all the bodies, sulphuric acid collects at the bottom of the flask ; take out a few drops of the liquid ; test in the usual way with barium chloride and hydrochloric acid.

Place the remainder in an evaporating basin and apply heat :

at first water is given off; finally dense suffocating fumes of sulphuric acid are evolved; remove the flame immediately these are perceived: a thick, oily-looking liquid remains.

In the manufacture of sulphuric acid the sulphur dioxide is usually produced by roasting sulphur ore (iron sulphide) in a furnace; in this way a mixture of sulphur dioxide and air is formed. In Fig. 37, A, A represent these furnaces; a pot *b* is placed in the current of heated gases; this contains a mixture of sodium nitrate and sulphuric acid, from

FIG. 37.



which nitric acid is evolved. A mixture, therefore, of air, nitric acid, and sulphur dioxide is conveyed into the chamber F, F, made of timber framing lined with sheet lead. Steam is generated in the boiler E, and conveyed by jets *c, c*, into the chamber. The floor *d, d*, is covered by a layer of water, which condenses the acid. In some manufactories instead of placing a mixture of sodium nitrate and sulphuric acid in the pot *b*, the acid only is placed in at first, and a solution of the nitrate added in a small stream; in this way a more constant and gradual evolution of nitric acid is maintained. The acid chambers vary from 150 to

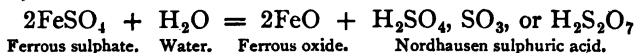
Manufacture and Properties of Sulphuric Acid. 179

300 feet in length ; they are about 12 or 15 feet high, and from 15 to 20 wide. From the waste flue C nothing but nitrogen from the air and nitric oxide should escape. The liquid which condenses at the bottom of the chamber is too dilute for most purposes, and is concentrated by evaporation in leaden pans, until it contains about only one-fifth of its weight of water ; at the temperature required for the expulsion of the remaining water, the leaden pans would probably melt ; the further concentration is effected either by heating in vessels of glass or of platinum.

Nordhausen sulphuric acid may be looked on as a compound of a molecule of ordinary sulphuric acid with a molecule of sulphur trioxide ; it is named after a town in Saxony, where it is prepared in large quantities by first drying ferrous sulphate, and at a stronger heat decomposing it. Supposing the whole of the water were removed before the decomposition of the salt, the change might be thus represented :—



It is impossible, however, to first drive off the whole of the water, and a portion of the sulphur trioxide being hydrated, the remainder is dissolved :—



The molecule of sulphur trioxide, in Nordhausen sulphuric acid, being only held in feeble combination, is readily driven off by heat.

PROPERTIES.—Sulphuric acid in the pure state is a colourless, odourless liquid of oily consistency. It has a specific gravity of 1·842, and boils at about 338° C. ; the high temperature of the boiling point renders the acid specially suitable for the preparation of the more volatile acids, as nitric acid, from their salts ; any excess of sulphuric acid and the resultant sulphate formed, being non-volatile at the temperature at which nitric acid boils, are thus easily separated.

Sulphuric acid has a very great attraction for water, with which it forms definite compounds ; the union of the two is attended with evolution of great heat.

Experiment 150.—Place not more than a cubic centimetre of water in a test-tube, and add to it the same quantity of the concentrated acid ; observe the heat developed, testing with a thermometer if one be available.

Experiment 151.—Place a small quantity of sulphuric acid in an evaporating basin, and let it remain for a week : notice that at the end of that time the acid will have increased in volume from the absorption of moisture from the air.

From the avidity with which sulphuric acid absorbs water, it is largely used in the laboratory as a drying agent for gases. It also attacks most organic bodies, removing from them the elements of water ; the preparation of carbon monoxide from oxalic and formic acids are examples of this action. When bodies have an excess of carbon, that element is deposited in the free state, as is the case with sugar.

Experiment 152.—Prepare a concentrated solution of sugar in water and about one-eighth fill a beaker with it ; add all at once twice the volume of sulphuric acid ; the mixture suddenly froths up, with great heat ; a charred carbonaceous mass remains.

Experiment 153.—With dilute sulphuric acid make some marks on a piece of writing paper, and dry it at a gentle heat ; as the water evaporates the acid carbonizes the paper.

Sulphuric acid, being a dibasic acid, forms two well-marked series of salts, the one of which is normal ; the other, still containing half the hydrogen, is acid.

At a white heat the acid is decomposed into water, sulphur dioxide, and oxygen.

Summary.

Sulphur Trioxide is a non-acid body produced by the union of sulphur dioxide with oxygen : the two combine when passed over red hot spongy platinum. It has no action on litmus, but

has a great affinity for water, with which it produces sulphuric acid.

Sulphuric acid is a compound of great importance; it is formed by the oxidation of sulphurous acid either by the atmosphere or oxidizing agents, as nitric acid, or hydroxyl.

Oxy-acids are considered by some chemists to contain hydroxyl. In oxidation by nitric acid the nitrogen peroxide formed oxidizes, a further quantity of sulphurous acid being reduced to nitric oxide, which is immediately reconverted into the higher oxide by the oxygen of the air. Sulphuric acid is manufactured by the reactions occurring between sulphur dioxide, oxygen, nitric acid, and steam. The dilute acid is concentrated by evaporation. Nordhausen sulphuric acid is prepared by heating ferrous sulphate. Sulphuric acid is a colourless, odourless liquid, having a great attraction for water. Being a dibasic acid it forms two series of salts called sulphates.

Laboratory Hints.

In experiment 146, instead of blowing a bulb on a piece of combustion tubing, a 'chloride of calcium' tube may be used; these are sold ready made. The apparatus necessary for experiment 148 should be obtained from the general apparatus in the laboratory. The cork fitted to the large flask should be soaked in melted paraffin. The instrument makers sell bladders which may be used for the sulphur dioxide; a bullock's bladder, however, answers equally well. To fit it up, soften the neck by soaking in water, pass a piece of glass tubing through, and bind round firmly with thin copper binding wire; the bladder must be *dry* when used, as otherwise the sulphur dioxide is dissolved. Do not fill it long before required for use, and, when done with, squeeze out any gas which remains; blow out the bladder with air, and again empty; this will get rid of the sulphur dioxide; the bladder should be put away full of air. In arranging the bladder under a weighted board, take care that it is so fixed that there is no danger of the weight rolling on to the other parts of the apparatus. The air may be stored in a similar bladder, or if there be an oxy-hydrogen lime-light apparatus at hand, the *oxygen* bag may be used; after the experiment *completely empty* the bag. The little gas

holder recommended for the nitric oxide is a very useful piece of apparatus in the laboratory. To prepare one take a deflagrating jar holding three pints or two quarts ; fit to the top a paraffined cork, through which bore a hole and pass a bent piece of glass tube. Get a beaker or other vessel an inch or two higher than the jar and of such a size that it easily slides up and down in it ; fill this with water, and slip over the glass leading tube a piece of india-rubber tubing and a screw tap. To fill the jar, attach the gas generating apparatus to the tube, the jar as it fills rises higher ; when filled, shut off the screw tap : the weight of the jar is sufficient to force the gas out of the holder as required.

QUESTIONS AND EXERCISES,

SELECTED PRINCIPALLY FROM

EXAMINATION PAPERS OF THE SCIENCE AND ART DEPARTMENT.

The numbers to the right are those of the pages on which answers to the questions may be found. The student should endeavour, however, to write his answers as far as possible in his own language.

	PAGE
1. Define 'chemistry,' 'element,' 'compound,' 'mixture.' 1 and 6	
2. Describe an experiment to illustrate the indestructibility of matter in the case of a burning candle. Give a drawing of the apparatus you would use. (S. and A. D. Ex. 1878.) ¹	
It is stated that matter is indestructible ; describe any experiments which confirm the truth of this statement. (S. and A. D. Ex. 1881.)	3
3. In what ways do a mixture of copper and sulphur differ after being heated from their condition previous to the application of heat ?	5
4. Describe the relation which exists between chemical action and the other forces, especially <i>heat</i>	7
5. What are the effects respectively of 'gravitation,' 'cohesion,' and 'chemical action' on matter?	7
6. In what way does chemical attraction differ from the other natural forces ? Mention some experiments which illustrate this difference.	11

¹ Science and Art Department Examination.

7. A wooden lath is suspended horizontally by means of a thread. A dry glass rod or tube is now briskly rubbed with warm silk, and then brought near to one end of the suspended lath; what occurs? (S. and A. D. Ex. 1876.) 12
8. What happens when a glass rod moistened with concentrated sulphuric acid is brought very near to a small heap of a mixture of sugar and potassic chlorate, but so as not to touch the heap? (S. and A. D. Ex. 1876.) 12
9. Mention and describe the different modes of chemical action. Give at least one experimental illustration of each. 13
10. What takes place when solution of mercuric chloride is added to solution of potassic iodide? (S. and A. D. Ex. 1875.) 14
11. A white powder is shaken up with distilled water; how would you ascertain whether any of it dissolves? (S. and A. D. Pract. Ex. 1880.) 16
12. A glass full of dirty water is given to you. Describe with sketch the plan you would adopt, first for rendering the water clear, and secondly, for ascertaining whether the clear water contains any dissolved solid matter. (S. and A. D. Ex. 1880.) 17
13. Describe fully how you would proceed in order to obtain pure water from sea water. 18
14. Explain the meaning of the terms 'sublimation,' 'volatile,' 'fixed,' and 'ignition.' 19
15. Give a short account of the metric system of weights and measures. 20
16. What do you understand by the *temperature* of a body, and how is it measured? 23
17. Describe the Fahrenheit and Centigrade scales. Convert 200° , and -10° C. into Fahrenheit; and 60° , and -40° F. into Centigrade degrees. 24
18. What is meant by *absolute temperature*? State the laws governing the relation of the volume of a gas to its pressure and temperature. 25
19. Classify the chief elementary substances into metals and

- non-metals and into positive and negative elements.
(S. and A. D. Ex. 1875.) 27 and 81
20. By what properties is a metal distinguished from a non-metal? Arrange the following elements under the above heads :—
Cl. K. P. S. N. Na. As. H. Fe. (S. and A. D. Ex. 1879.) 28
21. Mention the elements which at ordinary temperatures are respectively gases and liquids. State the approximate composition of the earth's crust. 28
22. Explain carefully what is meant by 'symbol,' 'formula,' and 'chemical equation.' 29
23. What is understood by the terms 'atom,' 'combining proportion,' 'combining weight,' and 'atomic weight'? 30
24. Give an account of the discovery of oxygen. 33
25. You have given to you some *red precipitate* (mercuric oxide); state (1) whether you consider this substance to be a simple or a compound body, (2) whether it undergoes any chemical change when submitted to the action of heat, and if so, (3) what is the nature of the change, and how it can be expressed symbolically. (S. and A. D. Ex. 1874.)
- How would you prove by experiment that mercuric oxide is a compound and not an elementary substance? Sketch and describe the apparatus you would use for this purpose. (S. and A. D. Ex. 1880.) 6, 34
26. I heat potassic chlorate in a flask until effervescence commences. What chemical change takes place? I then drop into the flask some peroxide of manganese. What happens? (S. and A. D. Ex. 1879.) . . . 34
27. What are the resulting products when hydrogen, carbon, sulphur, and phosphorus are burnt in oxygen? Express the reactions by equations. (S. and A. D. Ex. 1874.)
- I heat, as strongly as possible, a fragment of each of the following substances in a glass tube through which a current of air is passing: Sulphur, phosphorus, charcoal. What chemical changes take place? (S. and A. D. Ex. 1876.) 38 and 48

	PAGE
28. What are the principal properties of oxygen ? . . .	8
29. What takes place when electric sparks are passed through dry oxygen ? (S. and A. D. Ex. 1877.) . . .	39
30. What do you understand by an allotropic form of oxygen ? How is this substance distinguished from ordinary oxygen ? (S. and A. D. Ex. 1881.) . . .	39
31. Some moist phosphorus is placed in a jar filled with atmospheric air, and a slip of paper which has been dipped into water containing starch and potassic iodide is suspended in the jar. State what occurs. (S. and A. D. Ex. 1875.)	40
32. Sketch the apparatus you have seen used for preparing hydrogen (1) by the action of sodium on water (2) by that of zinc on sulphuric acid. (S. and A. D. Pract. Ex. 1881.)	45 and 47
33. Translate into words the following equation :— $2\text{OH}_2 + \text{K}_2 = 2\text{OKH} + \text{H}_2$ (S. and A. D. Ex. 1879.)	
The reaction is similar to that with Na.	45
34. Into a boiling solution of caustic soda I drop some fragments of granulated zinc. What chemical change, if any, takes place ? (S. and A. D. Ex. 1876.) . . .	46
35. Describe the chemical change which takes place when steam is passed over red hot iron filings.	47
36. Describe exactly how you would show the formation of water from burning hydrogen, and sketch the apparatus. (S. and A. D. Pract. Ex. 1880.)	48
37. What are the principal properties of hydrogen ? . . .	48
38. How would you prove the presence of solid and gaseous impurities in water ?	52
39. Describe carefully the changes produced by raising the temperature of a piece of ice from -10° to 150° C. . .	53
40. Explain the terms 'crystal,' 'dimorphous,' 'amorphous,' and 'water of crystallization.'	56
41. Describe an experiment for proving that water is a compound body, and state precisely the conclusions to which the experiment leads you. (S. and A. D. Ex. 1877.)	57
42. A mixture of five volumes of hydrogen and three	

- volumes of oxygen are exploded by an electric spark, will any gas remain? If so, how much, and how will you ascertain what it is? (S. and A. D. Ex. 1879.) 60
43. Describe an experiment by means of which you would prove the relation which exists between the volume of hydrogen and oxygen and of the steam produced by their combination. 61
44. What is the composition of water by weight, and how may it be experimentally determined? 62
45. What is the composition of hydroxyl, and how may it be prepared? 64
46. Give a description of the properties of hydroxyl. 66
47. What do you mean by the terms 'reducing' and 'oxidizing' agents? Give some examples of each. 67
48. Describe two processes for the preparation of chlorine. Give an equation and a sketch of the apparatus in each case. (S. and A. D. Ex. 1878.) 71
49. Three pint bottles of chlorine are given to you; describe the experiments you would make with them in order to show clearly the characteristic properties of this body. (S. and A. D. Ex. 1880.) 73
50. Hydrogen burns in chlorine. How would you make this experiment? Give a sketch. (S. and A. D. Pract. Ex. 1881.) 73
51. What happens when steam is passed through a red-hot porcelain tube, and when a mixture of steam and chlorine is passed through the same tube? (S. and A. D. Ex. 1877.) 75
52. Describe with a sketch the method you would employ for the preparation of hydrochloric acid: also give equations. 78
53. What are the principal properties of hydrochloric acid? 79
54. Hydrochloric acid is stated to be composed of equal volumes of chlorine and hydrogen united without condensation. How would you prove experimentally that this is the case—(a) by analysis; (b) by synthesis. (S. and A. D. Ex. 1878.) 80

55. Describe clearly why the formula H_2O has been given to water. 85
56. Explain what is understood by Dalton's atomic theory. (S. and A. D. Ex. 1881.) 86
57. Calculate the percentage composition of potassium chlorate (chlorate of potash.) ($K = 39$. $Cl = 35.37$. $O = 16$.) (S. and A. D. Ex. 1878.) 87
58. What is the percentage composition of water? (S. and A. D. Ex. 1875.) 87
59. What is the percentage composition of hydrochloric acid? (S. and A. D. Ex. 1874.) 87
60. What is the chemical formula of a body having the following percentage composition :—

S	.	.	.	32.65
O	.	.	.	65.31
H	.	.	.	2.04
				<hr/> 100.00

(S. and A. D. Ex. 1876.) 88

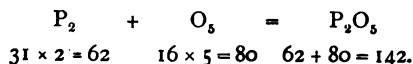
61. A body on analysis gave the following results, what is its formula?—

C	.	.	.	14.29
O	.	.	.	57.14
H	.	.	.	1.19
Na	.	.	.	27.38
				<hr/> 100.00

88

62. Air contains 23 per cent. of its weight of oxygen. How many grams of phosphorus are needed to burn out the whole of the oxygen in 100 grams of air when the highest oxide of phosphorus is formed? $P = 31$. (S. and A. D. Ex. 1878.)

From the question, there are 23 grams of O in 100 grams of air. The chemical action when P burns in O is represented in the following equation :—



To burn 80 by weight of O., 62 of P are required; then—

As 80 : 23 :: 62 : 17·8 grams of P required to burn out 23 grams of O. 89

63. How many milligrams of hydrogen are evolved when 460 milligrams of sodium ($\text{Na} = 23$) are thrown into water? Express the decomposition by an equation. (S. and A. D. Ex. 1877.) 89
64. Define Avogadro's law, and state what bearing it has on the composition by volume of compound gases. 94
65. What reasons have chemists for considering that the atoms of elementary gases combine together to form molecules; and why is the molecule of hydrogen assumed to consist of two atoms? 93, 94
66. What is a crith, and how is it employed by chemists? (S. and A. D. Ex. 1874.) 96
67. If 112 litres of hydrogen weigh ten grams, what is the weight in grams of the same volume of chlorine, and of the same volume of hydrochloric acid gas? (S. and A. D. Ex. 1880.) 96
68. Write out the various names by which the following compounds are known :— Fe_2O_3 , CuO , Cu_2O , BaO , Fe_3O_4 , NaHO , SO_3 , SO_2 , H_2SO_4 , H_2SO_3 , Na_2SO_3 , K_2SO_4 , KHSO_4 98
69. What are the characteristic properties of an acid and of a base? Explain the effect of mixing sulphuric acid and caustic soda. (S. and A. D. Ex. 1881.) 100
70. Express in words the meaning of the following equation :— $\text{OKH} + \text{HCl} = \text{KCl} + \text{OH}_2$. (S. and A. D. Ex. 1878.) 101
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73. Give the atomicity of each element in the following compounds :—
 $\text{HCl} - (\text{OH})_2 - \text{NH}_3 - \text{CO}_2 - \text{SO}_2$ and SH_2 . (S. and A. D. Ex. 1877.)
 $(\text{OH})_2 = \text{H}_2\text{O}_2$ 106

74. Indicate by graphic notation the atomicity of the following elements:—Nitrogen, sulphur, carbon, chlorine, oxygen, boron, silicon, bromine, phosphorus, zinc, and calcium. (S. and A. D. Ex. 1879.) . . . 106
75. Why must NO be written as the formula of nitric oxide; and in what way is it an exception to the general rule which governs the active atomicity of elements in a compound? State that rule. . . . 106
76. Define the terms 'monobasic' and 'dibasic' as applied to acids. Knowing the atomicity of the various metals, write the formulæ of the following salts:—Silver nitrate, gold chloride, copper nitrate, zinc sulphate, lead chloride, silver sulphate. . . . 107
77. Describe the allotropic forms of carbon. How would you prove that these different substances consist of the same element? (S. and A. D. Ex. 1877.) . . . 108
78. If twelve grams of pure carbon be completely burnt in the oxygen which is obtained by decomposing 122.5 grams of potassic chlorate, what is the weight of the product of the combustion formed, and what is the weight, if any, of oxygen remaining? (S. and A. D. Ex. 1880.)
- How many litres of carbon dioxide (carbonic anhydride) will be formed by the complete combustion of 12 grams of carbon, and how many litres of oxygen will be required? (S. and A. D. Ex. 1879.) . . . 112
79. Express in words the meaning of the following equation:— $\text{Ca}(\text{HO})_2 + \text{CO}_2 = \text{CO}(\text{CaO}_2) + \text{OH}_2$. (S. and A. D. Ex. 1874.) . . . 113
80. Quicklime is slaked with water, diffused through more water, and filtered. When carbonic anhydride gas is passed through the filtered liquid it becomes very turbid; what is the composition of the substance which causes the turbidity? Give an equation. (S. and A. D. Ex. 1879.) . . . 112
81. You are required to prove that carbon dioxide (carbonic acid gas) is formed when wood is burnt. Describe and sketch the apparatus you would use. (S. and A. D. Pract. Ex. 1881.) . . . 113

82. Describe the preparation of carbon dioxide, and give a sketch of its properties. 115
83. What weight of quicklime (calcium oxide) may be obtained from a ton of limestone? 115
84. Express in words the meaning of the following equation :—

$$\text{CaCO}_3 + 2\text{HCl} = \text{CaCl}_2 + \text{CO}_2 + \text{OH}_2$$
(S. and A. D. Ex. 1876.) 115
85. How would you demonstrate the fact that carbon dioxide (CO_2) is heavier than air? (S. and A. D. Pract. Ex. 1880.) 116
86. Air passes through a bright coke fire; describe the chemical changes which will occur, and the properties of any compounds that may be formed. (S. and A. D. Ex. 1881.) 119
87. You are required to prepare carbon monoxide and carbon dioxide from charcoal and air; sketch the apparatus you would use, and explain how it would differ in the two cases. By what tests would you distinguish these two gases? (S. and A. D. Pract. Ex. 1881.) 120
88. Represent by equation, and otherwise describe what happens when oxalic acid is heated with strong sulphuric acid. (S. and A. D. Ex. 1879.) 120
89. Oxalic acid is heated with sulphuric acid; how would you experimentally prove that the gases evolved are carbonic anhydride (CO_2), and carbonic oxide (CO)? (S. and A. D. Pract. Ex. 1880.) 120
90. You are required to prepare carbonic oxide; give a description of one process, a sketch of the apparatus, and an equation showing the nature of the chemical change. (S. and A. D. Ex. 1874.) 121
91. Lime-water is shaken up in a jar filled with carbonic oxide; what occurs? The carbonic oxide is then inflamed, and the lime-water once more shaken up with the contents of the jar. What now takes place? (S. and A. D. Ex. 1875.) 122
92. What are the principal properties of carbon monoxide? 122
93. Ten grams of oxalic acid are heated with sulphuric

acid ; what weight of carbon monoxide is evolved?
 If the resultant mixed gases be passed through a tube containing red-hot charcoal, so as to effect the complete conversion of the carbon dioxide into carbon monoxide, what weight of carbon monoxide will be produced? 120

94. How many volumes of carbon dioxide (carbonic acid gas) will be formed when a mixture of four volumes of carbon monoxide (carbonic oxide gas) and four volumes of oxygen is burnt? State what volume of oxygen, if any, remains uncombined. (S. and A. D. Ex. 1881.)

One volume of carbon monoxide (carbonic oxide) gas is mixed with two volumes of oxygen, and an electric spark passed through the mixture. What volume of carbon dioxide gas (carbonic anhydride) is formed, and what volume of oxygen left? (S. and A. D. Ex. 1877.) 122

95. Describe two methods for the preparation of nitrogen, expressing the reactions by equations, and giving drawings of the apparatus. (S. and A. D. Ex. 1877.) 124

96. Write an account of the principal properties of nitrogen.

What effect is produced by passing a series of electric sparks through a mixture of nitrogen and oxygen? 126

97. What is the composition of the atmosphere, and how may it be determined (1) by volume, (2) by weight? 127

98. Is air a mixture or a compound? Give reasons for your answer. 129

99. Describe three experiments, the best you can think of, one is to prove that the air contains oxygen, another that it contains carbon dioxide, and the third that it contains aqueous vapour. (S. and A. D. Ex. 1881.) 129

100. How would you prepare ammonia gas, and fill a jar with it? Give a sketch of the apparatus. (S. and A. D. Ex. 1875.)

How would you prepare ammonia? Sketch the apparatus you would use. In what respects does water saturated with ammonia differ from pure water? (S. and A. D. Ex. 1881.) 133

101. Draw the apparatus, and describe how you would prepare ammonia (NH_3) from ordinary solution of ammonia. (S. and A. D. Pract. Ex. 1880.) . . . 135
102. What takes place when a lighted taper is immersed in gaseous ammonia? (S. and A. D. Ex. 1874.) . . . 135
103. Ammonia gas is led into solution of hydrochloric acid. What is produced? Give an equation. The resulting liquid is evaporated to dryness in a porcelain crucible, which is afterwards heated to redness. What will remain in the crucible? (S. and A. D. Ex. 1879.) . . . 136
104. What is the percentage composition of ammoniac chloride? (S. and A. D. Ex. 1876.) . . . 136
105. Define a compound radical and give an example. (S. and A. D. Ex. 1875.) . . . 136
106. How would you ascertain that ammonia is a compound containing nitrogen and hydrogen? (S. and A. D. Ex. 1877.) . . . 137
107. Give an account of the occurrence and preparation of nitric acid. 139
108. Explain in words all that is expressed by the following equation :—

$$2\text{KNO}_3 + \text{H}_2\text{SO}_4 = 2\text{K}_2\text{SO}_4 + 2\text{HNO}_3$$
 (S. and A. D. Ex. 1881.) . . . 140
109. How many pounds of nitric acid can be obtained from 150 pounds of nitre (potassium nitrate), and how many grains of sulphuric acid will be needed? (S. and A. D. Ex. 1879.) . . . 140
110. I put some gold-leaf into a jar of nitric acid and into one of liquid hydrochloric acid; what takes place? I mix the contents of the two jars; what then occurs? (S. and A. D. Ex. 1876.) . . . 141
111. What changes take place when zinc dissolves in dilute nitric acid? (S. and A. D. Ex. 1876.) . . . 143
112. Carbonate of ammonia and nitric acid are given to you. How would you prepare nitrous oxide from these? Draw a sketch of the apparatus you would use, and give an equation showing the decomposition.

- tion which takes place in making the gas. (S. and A. D. Ex. 1879.) 144
113. What are the principal properties of nitrogen monoxide? Feebly-burning sulphur is extinguished when plunged into this gas, while, if brightly burning, it continues to do so with increased brilliancy; state clearly the reason for this. 144
114. Ten grams of nitric acid are neutralized by ammonia: what weight of nitrogen monoxide may be obtained from the ammonium nitrate thus produced? . . . 144
115. How would you prepare nitric oxide? Give the equation, and draw a sketch of the apparatus. . . . 146
116. By what properties would you recognise nitric oxide? Compare its power of supporting combustion with that of nitrogen monoxide. 147
117. I want 6 grams of nitric oxide; how much copper and nitric acid shall I require for its production? . . 146
118. What are the natural sources of sulphur, and how is it usually prepared on the large scale? 152
119. Describe the different varieties of sulphur, and how they may be prepared. 153
120. Describe the changes produced in brimstone by the continued application of heat. (S. and A. D. Ex. 1874.) 154
121. What weight of sulphur would you expect to obtain from ten tons of sulphur ore (ferric sulphide)? Allow what you consider a fair percentage for loss. . . 152
122. If I burn a piece of sulphur in a bottle filled with air, and another piece in a bottle filled with oxygen, what shall I find in each of the bottles after the combustion is finished? Give equations. (S. and A. D. Ex. 1878.) 155
123. Explain fully what is meant by the following equation:—

$$\text{H}_2\text{SO}_4 + \text{FeS} = \text{H}_2\text{S} + \text{FeSO}_4$$
(S. and A. D. Ex. 1880.) 157
124. How would you prove that the gas obtained by pouring sulphuric acid upon ferrous sulphide contains both sulphur and hydrogen? (S. and A. D. Ex. 1878.)

- Describe what you consider the best experimental proof that sulphur is a constituent of sulphuretted hydrogen. (S. and A. D. Ex. 1880.) 158
125. Sulphuretted hydrogen is passed into solutions of the following substances in different test-tubes—arsenious anhydride, lead acetate, zinc sulphate, antimony chloride, and ferrous sulphate. What is the result in each instance? 161
126. Give two methods for preparing the lower oxide of sulphur, and state its properties and its formula. Also explain how it can be converted into the higher oxide. (S. and A. D. Ex. 1880.) 164
127. Express in words the meaning of the following equation :— $\text{SO}_2 + \text{OH}_2 = \text{SO}(\text{OH})_2$. (S. and A. D. Ex. 1875.) 167
128. What are the principal uses of sulphur dioxide? 168
129. How would you prepare sulphur trioxide, and what are its properties? Give a sketch of the apparatus. 171
130. What is the weight of a litre (at 0°C . and 760 *m.m.* barometric pressure) of the vapour of a compound the normal molecule of which contains SO_3 ? (S. and A. D. Ex. 1875.) 171
131. To one test-tube containing water SO_3 has been added, to another SO_2 has been added; how would you determine which was which? Give the names and formulæ of the two bodies thus formed. (S. and A. D. Ex. 1881.) 173
132. Show, with a sketch, how you would prepare sulphuric acid experimentally. Describe, with equations, the theory of its production. 175
133. Describe, with a sketch, the commercial manufacture of sulphuric acid. 178
134. How much sulphuric acid may be made from one ton of FeS_2 ? (S. and A. D. Ex. 1874.) 178
135. What are the principal properties and uses of sulphuric acid? 179

MISCELLANEOUS.

136. Into separate test-glasses containing dilute hydrochloric acid I put the following substances :—Zinc, chalk, marble, common salt, charcoal, iron, and gold. Mention the chemical changes which take place, and give equations. (S. and A. D. Ex. 1878.)
Common salt and charcoal are unacted on.
137. What chemical effect is produced when a strong solution of hydrochloric acid in water is added to each of the following substances :—Zinc, iron, chalk, silver, sodic carbonate, gold? (S. and A. D. Ex. 1875.)
Silver is practically unacted on by strong hydrochloric acid in the cold.
138. What is the difference between a mixture of two elements and a compound of two elements? Why is atmospheric air declared to be a mixture and not a compound? (S. and A. D. Ex. 1874.)
139. I add sulphuric acid to a white salt and effervescence occurs. What may this be caused by, and what tests must I apply to ascertain the nature of the gas which is evolved. (S. and A. D. Ex. 1878.)
140. What happens when sulphuric acid is poured upon (1) rock salt, (2) chalk, (3) saltpetre? Give equations. (S. and A. D. Ex. 1877.)
141. How many grains of oxygen are contained in 1 lb. of each of the following compounds :—water, potassic chlorate carbonic oxide and ammonic nitrate? (S. and A. D. Ex. 1877.)
142. Write down in equations the changes which occur :—
(1.) When a mixture of iron filings and sulphur is heated.
(2.) When iron wire is burnt in oxygen.
(3.) When sulphur is burnt in the air. (S. and A. D. Ex. 1881.)
143. Draw the graphic formulæ of water, hydrochloric acid, hydroxyl, nitric acid, and sulphuric acid. (S. and A. D. Ex. 1877.)

Draw the graphic formulæ of the following compounds, and

mention the atomicity of each element contained in them :—Potassic chlorate, metaboric acid, carbonic anhydride, nitrous acid, and sulphuric anhydride. (S. and A. D. Ex. 1876.)

Draw the graphic formulæ of the following compounds, and mention the atomicity of each element present therein :—Hypochlorous acid, ammonia, sulphuric acid, boric anhydride, nitric acid, carbonic oxide. (S. and A. D. Ex. 1874.)

Draw the graphic formulæ of the following compounds :—Ammonia, water, sulphuretted hydrogen. Give the active atomicity of each element in the following compounds :— CH_4 , SO_2H_2 , PF_3 , CrF_6 , and SO_2 . (S. and A. D. Ex. 1878.)

Translate the following symbolic formulæ into graphic formulæ :— HI , NH_3 , SO_2H_2 , $\text{Ca}(\text{OH})_2$, NH_4Cl , $(\text{SO}_2)_3(\text{Fe}_2\text{O}_6)^{\text{VI}}$. (S. and A. D. Ex. 1875.)

Hydroxyl, $\text{H}-\text{O}-\text{O}-\text{H}$.

Metaboric acid, $\text{O}=\text{B}-\text{O}-\text{H}$.

Potassic chlorate, $\text{Cl}-\text{O}-\text{O}-\text{O}-\text{K}$.

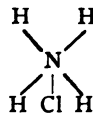
Nitrous acid, $\text{O}=\text{N}-\text{O}-\text{H}$.

Hypochlorous acid, $\text{Cl}-\text{O}-\text{H}$.

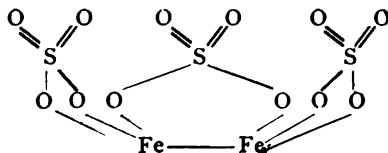
Hydriodic acid, HI . $\text{H}-\text{I}$.

Calcium hydrate, $\text{Ca}(\text{OH})_2$. $\text{H}-\text{O}-\text{Ca}-\text{O}-\text{H}$.

Ammonium chloride, NH_4Cl .



Ferric sulphate, $(\text{SO}_2)_3(\text{Fe}_2\text{O}_6)^{\text{VI}}$.



144. Divide the following substances into elements and compounds :—Diamond, graphite, charcoal, glass, lime, ozone, iron, gold, water, ammonia, and flint. (S. and A. D. Ex. 1876.)

145. Classify the following substances into elements and compounds :—Steam, ice, sulphur, hydroxyl, ammonia, common salt, marble, and carbonic anhydride. (S. and A. D. Ex. 1878.)
146. How many milligrams of hydrogen will be formed (1) when 230 milligrams of sodium are thrown on water, (2) when 649 milligrams of zinc are dissolved in sulphuric acid. (S. and A. D. Ex. 1881.)
147. I put slips of litmus and turmeric paper into (1) dilute nitric acid, (2) solution of potash, (3) solution of ammonia, (4) solution of carbonic anhydride, and (5) solution of potassic chloride. Describe what occurs in each case. (S. and A. D. Ex. 1875.)
148. Describe accurately and fully the changes, if any, which occur when the following bodies are heated in a test-tube over a gas flame; (a) ammonium chloride (sal ammoniac), (b) sulphur, (c) graphite, (d) ammonia solution. (S. and A. D. Ex. 1880.)
149. State which of the following substances are solid, liquid, or gaseous at the freezing point of water :—Sulphurous anhydride, ammonia, sulphuric anhydride, chlorine, nitric oxide, nitric acid, sulphuretted hydrogen, and hydroxyl. (S. and A. D. Ex. 1876.)
150. In what way would you remove a small amount of moisture from the following gases :—Air, ammonia, and carbon dioxide? (S. and A. D. Pract. Ex. 1881.)
151. What is the action of water upon each of the following substances :—Hydrogen, carbonic anhydride, ammonia, sodic carbonate, chalk, and sodium? (S. and A. D. Ex. 1874.)
152. How would you prepare the following gases— CO_2 , NH_3 , HCl , in a dry and pure state? Give the equations. Also how would you fill a small bottle with each? (S. and A. D. Ex. 1880.)
153. Name the chief properties of nitric acid. Point out in what respects nitric and sulphuric acids have similar properties, and, on the other hand, what differences there are which enable you readily to distinguish the one acid from the other. (S. and A. D. Ex. 1880.)

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